BRITISH STANDARD

BS EN 60825-1:2007

Safety of laser products —

Part 1: Equipment classification and requirements

The European Standard EN 60825-1:2007 has the status of a British Standard

ICS 13.280; 31.260

British Standards

National foreword

This British Standard is the UK implementation of EN 60825-1:2007. It is identical to IEC 60825-1:2007. It supersedes BS EN 60825-1:1994 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EPL/76, Optical radiation safety and laser equipment.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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English version

Safety of laser products - Part 1: Equipment classification and requirements (IEC 60825-1:2007)

Sécurité des appareils à laser -
Partie 1: Classification des matériels
et exigences
(CEI 60825-1:2007)

Sicherheit von Lasereinrichtungen -
Teil 1: Klassifizierung von Anlagen
und Anforderungen
(IEC 60825-1:2007)

This European Standard was approved by CENELEC on 2007-09-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

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Foreword

The text of document 76/338/CDV, future edition 2 of IEC 60825-1, prepared by IEC TC 76, Optical radiation safety and laser equipment, was submitted to the IEC-CENELEC parallel Unique Acceptance Procedure and was approved by CENELEC as EN 60825-1 on 2007-09-01.

This European Standard partially supersedes EN 60825-1:1994 (+ corrigendum February 1995) + A1:2002 + A2:2001 (+ corrigendum April 2004).

The user's guide has been removed from this part of the EN 60825 series and is now a separate document (Part 14). Light emitting diodes (LEDs) have been removed from the scope of this part of EN 60825, but may still be included in other parts.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2008-06-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2010-09-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60825-1:2007 was approved by CENELEC as a European Standard without any modification.

CONTENTS

SAFETY OF LASER PRODUCTS –

Part 1: Equipment classification and requirements

1 Scope and object

IEC 60825-1 is applicable to safety of laser products emitting laser radiation in the wavelength range 180 nm to 1 mm.

A laser product may consist of a single laser with or without a separate power supply or may incorporate one or more lasers in a complex optical, electrical, or mechanical system. Typically, laser products are used for demonstration of physical and optical phenomena, materials processing, data reading and storage, transmission and display of information, etc. Such systems have found use in industry, business, entertainment, research, education, medicine and consumer products.

Laser products that are sold to other manufacturers for use as components of any system for subsequent sale are not subject to IEC 60825-1, since the final product will itself be subject to this standard. However, if the laser system within the laser product is operable when removed from the equipment, the requirements of this Part 1 apply to the removable unit.

NOTE 1 Operable equipment does not require a tool to prepare for operation.

Any laser product is exempt from all further requirements of this Part 1 if classification by the manufacturer of that product according to Clauses 3, 8 and 9 shows that the emission level does not exceed the AEL (accessible emission limit) of Class 1 under all conditions of operation, maintenance, service and failure.

NOTE 2 The above exemption is to ensure that inherently safe laser products are not unnecessarily subject to the standard.

In addition to the hazards resulting from laser radiation, laser equipment may also give rise to other hazards such as fire and electric shock.

NOTE 3 However, the classification and other requirements of this standard are intended to address only the laser radiation hazards to the eyes and skin. Other hazards are not included within its scope.

This Part 1 describes the minimum requirements. Compliance with this Part 1 may not be sufficient to achieve the required level of product safety. Laser products must conform to the applicable performance and testing requirements of the applicable product safety standards.

NOTE 4 Other standards may contain additional requirements. Consideration should also be given to the intended application and user group. For example, a class 3B or class 4 laser product may not be suitable for use as a consumer product.

Where a laser system forms a part of equipment which is subject to another IEC product safety standard (e.g. for medical equipment (IEC 60601-2-22), IT equipment (IEC 60950), audio and video equipment (IEC 60065), equipment for use in hazardous atmospheres (IEC 60079), or electric toys (IEC 62115)), this Part 1 will apply in accordance with the provisions of IEC Guide 104 [1)] for hazards resulting from laser radiation. If no product safety standard is applicable, then IEC 61010-1 applies.

In previous editions, LEDs were included in the scope of IEC 60825-1, and they may be still included in other parts of the IEC 60825 series. However, with the development of lamp safety standards, optical radiation safety of LEDs in general can be more appropriately addressed by lamp safety standards. The removal of LEDs from the scope of this Part 1 does not preclude other standards from including LEDs whenever they refer to lasers. CIE S009 may be applied to determine the risk group class of an LED or product incorporating one or more LEDs.

The MPE (maximum permissible exposure) values of this Part 1 were developed for laser radiation and do not apply to collateral radiation. However, if a concern exists that accessible collateral radiation might be hazardous, the laser MPE values may be applied to conservatively evaluate this potential hazard.

The MPE values are not applicable to intentional human exposure to laser radiation for the purpose of medical or cosmetic/aesthetic treatment.

NOTE 5 Annexes A to H have been included for purposes of general guidance and to illustrate many typical cases. However, the annexes are not regarded as definitive or exhaustive and reference should always be made to the appropriate clause(s) in the normative part of this document.

The objectives of this part of IEC 60825 are the following:

- to introduce a system of classification of lasers and laser products according to their degree of optical radiation hazard in order to aid hazard evaluation and to aid the determination of user control measures;
- to establish requirements for the manufacturer to supply information so that proper precautions can be adopted;
- to ensure, through labels and instructions, adequate warning to individuals of hazards associated with accessible radiation from laser products;
- to reduce the possibility of injury by minimizing unnecessary accessible radiation and to give improved control of the laser radiation hazards through protective features.

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1) IEC Guide 104:1997, *The preparation of safety publications and the use of basic safety publications and group safety publications*

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-845:1987, *International Electrotechnical Vocabulary (IEV) – Chapter 845: Lighting*

IEC 60601-2-22, *Medical electrical equipment – Part 2: Particular requirements for the safety of diagnostic and therapeutic laser equipment*

IEC 61010-1, *Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the definitions of IEC 60050-845 as well as the following apply.

NOTE For convenience here, the definitions have been arranged in English alphabetical order. Departures from IEC 60050-845 are intentional and are indicated. In such cases, reference is made, between brackets, to the definition of Part 845 of IEC 60050, with the mention "modified".

3.1
access panel
part of the protective housing or enclosure which provides access to laser radiation when removed or displaced

3.2
accessible emission
level of radiation determined at a position and with aperture stops (when the AEL is given in units of Watts or Joules) or limiting apertures (when the AEL is given in units of $W \cdot m^{-2}$ or $J \cdot m^{-2}$) as described in Clause 9

The accessible emission is determined where human access is considered, as specified in Definition 3.37. The accessible emission is compared with the accessible emission limit (Definition 3.3) in order to determine the class of the laser product. In the body of the standard, whenever the term "emission level" is used, it is to be understood as accessible emission.

NOTE When the beam diameter is larger than the aperture stop, the accessible emission when given in units of Watts or Joules is less than the total emitted power or energy of the laser product. When the beam diameter is smaller than the diameter of the limiting aperture, the accessible emission when given in units of $W \cdot m^{-2}$ or $J \cdot m^{-2}$, i.e. as irradiance or radiant exposure averaged over the limiting aperture, is smaller than the actual irradiance or radiant exposure of the beam. See also aperture stop (3.9) and limiting aperture (3.52).

3.3
accessible emission limit
AEL
the maximum accessible emission permitted within a particular class

NOTE Wherever the text refers to "emission level not exceeding the AEL" or similar wording, it is implicit that the accessible emission is determined following the measurement criteria specified in Clause 9.

3.4
administrative control
safety measures of a non-engineering type such as: key supervision, safety training of personnel, warning notices, count-down procedures, and range safety controls

3.5
alpha min
α_{min}
see angular subtense and minimum angular subtense (see 3.7 and 3.58)

3.6
angle of acceptance
plane angle within which a detector will respond to optical radiation, usually measured in radians

This angle of acceptance may be controlled by apertures or optical elements in front of the detector (see Figure 3 and 4). The angle of acceptance is also sometimes referred to as the field of view.

Symbol: γ

3.7
angular subtense of the apparent source
α
angle subtended by an apparent source as viewed from a point in space, as shown in Figure 3

NOTE 1 The location and angular subtense of the apparent source depends on the viewing position in the beam (see 3.11).

NOTE 2 The angular subtense of an apparent source is applicable in this Part 1 only in the wavelength range from 400 nm to 1 400 nm, the retinal hazard region.

NOTE 3 The angular subtense of the source should not be confused with the divergence of the beam. The angular subtense of the source can not be larger than the divergence of the beam but it is usually smaller than the divergence of the beam.

3.8
aperture
any opening in the protective housing or other enclosure of a laser product through which laser radiation is emitted, thereby allowing human access to such radiation

See also limiting aperture (3.52).

3.9
aperture stop
opening serving to define the area over which radiation is measured

3.10
apparent source
for a given evaluation location of the retinal hazard, the real or virtual object that forms the smallest possible retinal image (considering the accommodation range of the human eye)

NOTE 1 The accommodation range of the eye is assumed to be variable from 100 mm to infinity. The location of the apparent source for a given viewing position in the beam is that location to which the eye accommodates to produce the most hazardous retinal irradiance condition.

NOTE 2 This definition is used to determine, for a given evaluation position, the location of the apparent origin of laser radiation in the wavelength range of 400 nm to 1 400 nm. In the limit of vanishing divergence, i.e. in the case of a well collimated beam, the location of the apparent source goes to infinity.

3.11
beam
laser radiation that may be characterized by direction, divergence, diameter or scan specifications

Scattered radiation from a non-specular reflection is not considered to be a beam.

3.12
beam attenuator
device which reduces the laser radiation to or below a specified level

3.13
beam diameter
beam width
the beam diameter d_u at a position in space is the diameter of the smallest circle which contains u % of the total laser power (or energy)

For the purpose of this standard d_{63} is used.

NOTE 1 In the case of a Gaussian beam, d_{63} corresponds to the point where the irradiance (radiant exposure) falls to 1/e of its central peak value.

NOTE 2 The second moment diameter definition (as defined in ISO 11146-1) is not used for beam profiles with central high irradiance peaks and a low level background, such as produced by unstable resonators in the far field: the power that passes through an aperture can be significantly underestimated when using the 2nd moment and calculating the power with the assumption of a Gaussian beam profile.

3.14
beam divergence
far field plane angle of the cone defined by the beam diameter

If the beam diameters (see 3.13) at two points separated by a distance r are d_{63} and d'_{63} the divergence is given by:

$$\varphi = 2 \arctan\left(\frac{d'_{63} - d_{63}}{2r}\right)$$

SI unit: radian

NOTE The second moment divergence definition (ISO 11146-1) is not used for beam profiles with central high irradiance peaks and a low level background, such as produced by unstable resonators in the far field or beam profiles that show diffraction patterns caused by apertures.

3.15
beam expander
combination of optical elements which will increase the diameter of a laser beam

3.16
beam path component
optical component which lies on a defined beam path (e.g. a beam steering mirror or a focusing lens)

3.17
beam stop
device which terminates a laser beam path

3.18
Class 1 laser product
any laser product which during operation does not permit human access to accessible laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission durations (see 8.2 and 8.3 e))

NOTE 1 See also the limitations of the classification scheme in Annex C.

NOTE 2 As tests for the determination of the classification of the product are limited to tests during operation, it may be the case for embedded laser products that, depending on the product, radiation above the AEL of Class 1 can become accessible during maintenance when interlocks of access panels are overridden.

3.19
Class 1M laser product
any laser product in the wavelength range from 302,5 nm to 4 000 nm which during operation does not permit human access to accessible laser radiation in excess of the accessible emission limits of Class 1 for applicable wavelengths and emission durations (see 8.3e)), where the level of radiation is measured according to 9.2 g)

NOTE 1 See also the limitations of the Classification scheme in Annex C.

NOTE 2 Since the evaluation is with a smaller measurement aperture or at a greater distance from the apparent source than those used for Class 1 laser products, the output of a Class 1M laser product is therefore potentially hazardous when viewed using an optical instrument (see 8.2).

NOTE 3 As tests for the determination of the classification of the product are limited to tests during operation, it may be the case for embedded laser products that, depending on the product, radiation above the AEL of Class 1M can become accessible during maintenance when interlocks of access panels are overridden.

3.20
Class 2 laser product
any laser product in the wavelength range from 400 nm to 700 nm which during operation does not permit human access to accessible laser radiation in excess of the accessible emission limits of Class 2 for applicable wavelengths and emission durations (see 8.2 and 8.3e))

NOTE 1 See also the limitations of the Classification scheme in Annex C.

NOTE 2 As tests for the determination of the classification of the product are limited to tests during operation, it may be the case for embedded laser products that, depending on the product, radiation above the AEL of Class 2 can become accessible during maintenance when interlocks of access panels are overridden.

3.21
Class 2M laser product
any laser product in the wavelength range from 400 nm to 700 nm which during operation does not permit human access to accessible laser radiation in excess of the accessible emission limits of Class 2 for applicable wavelengths and emission durations (see 8.3 e)), where the level of radiation is measured according to 9.2 h)

NOTE 1 See also the limitations of the Classification scheme in Annex C.

NOTE 2 Since the evaluation is with a smaller measurement aperture or at a greater distance from the apparent source than those used for Class 2 laser products, the output of a Class 2M product is therefore potentially hazardous when viewed using an optical instrument (see 8.2).

NOTE 3 As tests for the determination of the classification of the product are limited to tests during operation, it may be the case for embedded laser products that, depending on the product, radiation above the AEL of Class 2M can become accessible during maintenance when interlocks of access panels are overridden.

3.22
Class 3R and Class 3B laser products
any laser product which during operation permits human access to laser radiation in excess of the accessible emission limits of Class 1 and Class 2, as applicable, but which does not permit human access to laser radiation in excess of the accessible emission limits of Classes 3R and 3B (respectively) for any emission duration and wavelength (see 8.2)

NOTE 1 See also the limitations of the Classification scheme in Annex C.

NOTE 2 Class 1M and Class 2M products may have outputs above or below the AEL of Class 3R, depending on their optical characteristics.

3.23
Class 4 laser product
any laser product which permits human access to laser radiation in excess of the accessible emission limits of Class 3B (see 8.2)

3.24
collateral radiation
any electromagnetic radiation, within the wavelength range between 180 nm and 1 mm, except laser radiation, emitted by a laser product as a result of, or physically necessary for, the operation of a laser

3.25
collimated beam
beam of radiation with very small angular divergence or convergence

3.26
continuous wave
CW
in this Part 1, a laser operating with a continuous output for a duration equal to or greater than 0,25 s is regarded as a CW laser

3.27
defined beam path
intended path of a laser beam within the laser product

3.28
demonstration laser product
any laser product designed, manufactured, intended or promoted for purposes of demonstration, entertainment, advertising, display or artistic composition

The term "demonstration laser product" does not apply to laser products which are designed and intended for other applications, although they may be used for demonstrating those applications.

3.29
diffuse reflection
change of the spatial distribution of a beam of radiation by scattering in many directions by a surface or medium

A perfect diffuser destroys all correlation between the directions of the incident and emergent radiation.

[IEV 845-04-47, modified]

3.30
embedded laser product
in this Part 1, a laser product which, because of engineering features limiting the accessible emission, has been assigned a class number lower than the inherent capability of the laser incorporated

NOTE The laser which is incorporated in the embedded laser product is called the embedded laser.

3.31
emission duration
temporal duration of a pulse, of a train or series of pulses, or of continuous operation, during which human access to laser radiation could occur as a result of operation, maintenance or servicing of a laser product

For a single pulse, this is the duration between the half-peak power point of the leading edge and the corresponding point on the trailing edge. For a train of pulses (or subsections of a train of pulses), this is the duration between the first half-peak power point of the leading pulse and the last half-peak power point of the trailing pulse.

3.32
errant laser radiation
laser radiation which deviates from a defined beam path

Such radiation includes unwanted reflections from beam path components and deviant radiation from misaligned or damaged components.

3.33
exposure duration
duration of a pulse, or series, or train of pulses or of continuous emission of laser radiation incident upon the human body

For a train of pulses, this is the duration between the first half-peak power point of the leading pulse and the last half-peak power point of the trailing pulse.

3.34
extended source viewing
viewing conditions whereby the apparent source at a distance of 100 mm or more subtends an angle at the eye greater than the minimum angular subtense (α_{min})

Two extended source conditions are considered in this standard when considering retinal thermal injury hazards: intermediate source and large source. They are used to distinguish sources with angular subtenses of the apparent source, α, between α_{min} and α_{max} (intermediate sources), and greater than α_{max} (large sources). (See also 3.80)

Examples are viewing of some diffused laser sources, diffuse reflections and of some laser diode arrays.

3.35
fail safe
design consideration in which failure of a component does not increase the hazard

In the failure mode the system is rendered inoperative or non-hazardous.

3.36
fail safe safety interlock
interlock which in the failure mode does not defeat the purpose of the interlock; for example, an interlock which is positively driven into the OFF position as soon as a hinged cover begins to open, or before a detachable cover is removed, and which is positively held in the OFF position until the hinged cover is closed or the detachable cover is locked in the closed position

3.37
human access
a) ability of the human body to meet laser radiation emitted by the laser product, i.e. radiation that can be intercepted outside of the protective housing, or

b) ability of a cylindrical probe with a diameter of 100 mm and a length of up to 100 mm to intercept levels of radiation of Class 3B and below, or

c) ability of a human hand or arm to intercept levels of radiation above the AEL of Class 3B,

d) also, for levels of radiation within the housing that are equivalent to Class 3B or Class 4, ability of any part of the human body to meet hazardous laser radiation that can be reflected directly by any single introduced flat surface from the interior of the product through any opening in its protective housing

NOTE For laser products that provide walk-in access, it is necessary to consider radiation both inside and outside of the protective housing for the determination of human access. Human access inside the housing can be prevented by engineering controls such as automatic detection systems.

3.38
integrated radiance
integral of the radiance over a given exposure duration expressed as radiant energy per unit area of a radiating surface per unit solid angle of emission

(usually expressed in $J \cdot m^{-2} \cdot sr^{-1}$)

3.39
intrabeam viewing
all viewing conditions whereby the eye is exposed to the direct or specularly reflected laser beam in contrast to viewing of, for example, diffuse reflections

3.40
irradiance
quotient of the radiant flux dΦ incident on an element of a surface by the area dA of that element

$$E = \frac{d\Phi}{dA}$$

Symbol: E
SI unit: watt per square metre ($W \cdot m^{-2}$)

3.41
laser
any device which can be made to produce or amplify electromagnetic radiation in the wavelength range from 180 nm to 1 mm primarily by the process of controlled stimulated emission

[IEV 845-04-39, modified]

3.42
laser controlled area
area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards

3.43
laser energy source
any device intended for use in conjunction with a laser to supply energy for the excitation of electrons, ions or molecules

General energy sources such as electrical supply mains or batteries are not considered to constitute laser energy sources.

3.44
laser hazard area
see nominal ocular hazard area (3.61)

3.45
laser product
any product or assembly of components which constitutes, incorporates or is intended to incorporate a laser or laser system

3.46
laser radiation
all electromagnetic radiation emitted by a laser product between 180 nm and 1 mm which is produced as a result of stimulated emission

3.47
laser safety officer
one who is knowledgeable in the evaluation and control of laser hazards and has responsibility for oversight of the control of laser hazards

3.48
laser system
laser in combination with an appropriate laser energy source with or without additional incorporated components

3.49
light emitting diode
LED
any semiconductor p-n junction device which can be made to produce electromagnetic radiation by radiative recombination in the semiconductor in the wavelength range from 180 nm to 1 mm

(The optical radiation is produced primarily by the process of spontaneous emission, although some stimulated emission may be present.)

3.50
limiting angle of acceptance for evaluating retinal photochemical hazards
for evaluation of the retinal photochemical hazard, a limiting measurement angle of acceptance, γ_{ph}, is specified. The angle γ_{ph} is related to eye movements and is not dependent upon the angular subtense of the source. If the angular subtense of the source is larger than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance γ is limited to γ_{ph} and the source is scanned for hotspots. If the measurement angle of acceptance γ is not limited to the specified level, the hazard may be over-estimated

NOTE If the angular subtense of the apparent source is smaller than the specified limiting angle of acceptance, the actual measurement angle of acceptance does not affect the measurement and does not have to be limited, i.e. a regular "open" angle of acceptance radiometer set-up can be used.

Symbol: γ_{ph}

3.51
limiting angle of acceptance for evaluating thermal hazards
the maximum angular subtense to be used for the evaluation of the retinal thermal hazard

The value of the angle of acceptance γ may vary between α_{min} and α_{max} (see 8.3 d); 9.3.2 b) 2)).

Symbol: γ_{th}

3.52
limiting aperture
circular area over which irradiance and radiant exposure are averaged

3.53
maintenance
performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser product, which are to be performed by the user for the purpose of assuring the intended performance of the product

It does not include operation or service.

3.54
maximum angular subtense
α_{max}
value of angular subtense of the apparent source above which the MPEs and AELs are independent of the source size

NOTE α_{max} = 100 mrad

3.55
maximum output
maximum radiant power, and where applicable, the maximum radiant energy per pulse, of the total accessible laser radiation emitted in any direction by a laser product over the full range of operational capability at any time after manufacture

NOTE The maximum output is the maximum accessible emission that is used to determine the class of the laser product. Since the determination of the accessible emission includes, besides other conditions, considering single fault conditions (see 9.2), the maximum output may exceed the highest output during normal operation.

3.56
maximum permissible exposure
MPE
level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects

The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the laser radiation, the pulse duration or exposure duration, the tissue at risk and, for visible and near infra-red laser radiation in the range 400 nm to 1 400 nm, the size of the retinal image. Maximum permissible exposure levels are (in the existing state of knowledge) specified in Annex A.

3.57
medical laser product
any laser product designed, manufactured, intended or promoted for purposes of *in vivo* diagnostic, surgical, or therapeutic laser irradiation of any part of the human body

3.58
minimum angular subtense
α_{min}
value of angular subtense of the apparent source above which a source is considered an extended source

MPEs and AELs are independent of the source size for angular subtenses less than α_{min}.

NOTE α_{min} = 1,5 mrad

3.59
mode-locking
regular mechanism or phenomenon, within the laser resonator, producing a train of very short (e.g. sub-nanosecond) pulses

While this may be a deliberate feature it can also occur spontaneously as "self-mode-locking". The resulting peak powers may be significantly greater than the mean power.

3.60
most restrictive position
position in the beam where the ratio of accessible emission over AEL is maximum

NOTE Both the accessible emission and the AEL may depend on the position of the evaluation in respect to the beam.

3.61
nominal ocular hazard area
NOHA
area within which the beam irradiance or radiant exposure exceeds the appropriate corneal maximum permissible exposure (MPE), including the possibility of accidental misdirection of the laser beam

If the NOHA includes the possibility of viewing through optical aids, this is termed the "extended NOHA".

3.62
nominal ocular hazard distance
NOHD
distance from the output aperture at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE)

If the NOHD includes the possibility of viewing through optical aids, this is termed the "extended NOHD (ENOHD)".

3.63
operation
performance of the laser product over the full range of its intended functions

It does not include maintenance or service.

3.64
photochemical hazard limit
either an MPE or AEL which was derived to protect persons against adverse photochemical effects

In the ultraviolet wavelength range, the photochemical hazard limit protects against adverse effects on the cornea and lens, while the retinal photochemical hazard limit, as defined in the wavelength range from 400 nm to 600 nm, protects against photoretinitis – a photochemical retinal injury from exposure to radiation.

3.65
protective enclosure
physical means for preventing human exposure to laser radiation, unless such access is necessary for the intended functions of the installation

3.66
protective housing
those portions of a laser product (including a product incorporating an embedded laser) which are designed to prevent human access to laser radiation in excess of the prescribed AEL (generally installed by a manufacturer)

3.67
pulse duration
time increment measured between the half peak power points at the leading and trailing edges of a pulse

3.68
pulsed laser
laser which delivers its energy in the form of a single pulse or a train of pulses

In this Part 1, the duration of a pulse is less than 0,25 s.

3.69
radiance
quantity defined by the formula

$$L = \frac{\mathrm{d}\Phi}{\mathrm{d}A \cdot \cos\theta \cdot \mathrm{d}\Omega}$$

where

$\mathrm{d}\Phi$ is the radiant flux transmitted by an elementary beam passing through the given point and propagating in the solid angle $\mathrm{d}\Omega$ containing the given direction;

$\mathrm{d}A$ is the area of a section of that beam containing the given point;

θ is the angle between the normal to that section and the direction of the beam

Symbol: L

SI unit: $\mathrm{W \cdot m^{-2} \cdot sr^{-1}}$

[IEV 845-01-34, modified]

NOTE This definition is a simplified version of IEV 845-01-34, sufficient for the purpose of this Part 1. In cases of doubt, the IEV definition should be followed.

3.70
radiant energy
time integral of the radiant flux over a given duration Δt

$$Q = \int_{\Delta t} \Phi \mathrm{d}t$$

[IEV 845-01-27]

Symbol: Q
SI unit: joule (J)

3.71
radiant exposure
at a point on a surface, the radiant energy incident on an element of a surface divided by the area of that element

$$H = \frac{\mathrm{d}Q}{\mathrm{d}A} = \int E \mathrm{d}t$$

Symbol: H
SI unit: joule per square metre ($\mathrm{J \cdot m^{-2}}$)

3.72
radiant power
radiant flux
power emitted, transferred, or received in the form of radiation

$$\Phi = \frac{\mathrm{d}Q}{\mathrm{d}t}$$

[IEV 845-01-24]

Symbol: Φ, P
SI unit: watt (W)

3.73
reflectance
ratio of the reflected radiant power to the incident radiant power in the given conditions
[IEV 845-04-58, modified]

Symbol: ρ
SI unit: 1

3.74
remote interlock connector
connector which permits the connection of external controls placed apart from other components of the laser product (see 4.4)

3.75
safety interlock
automatic device associated with each portion of the protective housing of a laser product to prevent human access to Class 3R, Class 3B or Class 4 laser radiation when that portion of the housing is removed, opened or displaced (see 4.3)

3.76
scanning laser radiation
laser radiation having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference

3.77
service
performance of those procedures or adjustments described in the manufacturer's service instructions, which may affect any aspect of the product's performance

It does not include maintenance or operation.

3.78
service panel
access panel that is designed to be removed or displaced for service

3.79
single fault condition
any single fault that might occur in a product and the direct consequences of that fault

3.80
small source
source with an angular subtense α less than, or equal to, the minimum angular subtense α_{min}

3.81
specular reflection
reflection from a surface that can be considered a beam (see 3.11), including reflections from mirrored surfaces

NOTE This definition is intended to recognise that some reflecting surfaces, such as parabolic reflectors, may increase the hazard from an incident beam, or at least leave it unchanged.

3.82
thermal hazard limit
either an MPE or AEL which was derived to protect persons against adverse thermal effects, as opposed to photochemical injury

3.83
time base
emission duration to be considered for classification of laser products (see 8.3 e))

3.84
tool
denotes a screwdriver, hexagonal key or other object which may be used to operate a screw or similar fixing means

3.85
transmittance
ratio of the transmitted radiant flux to the incident flux in the given conditions

[IEV 845-04-59, modified]

Symbol: τ
SI unit: 1

3.86
transmittance (optical) density
logarithm to base ten of the reciprocal of the transmittance τ

[IEV 845-04-66]

$$D = -\log_{10} \tau$$

Symbol: D

3.87
visible radiation (light)
any optical radiation capable of causing a visual sensation directly

[IEV 845-01-03]

NOTE In this Part 1, this is taken to mean electromagnetic radiation for which the wavelengths of the monochromatic components lie between 400 nm and 700 nm.

3.88
workpiece
an object intended for processing by laser radiation

4 Engineering specifications

4.1 General remarks

Laser products require certain built-in safety features, depending on the class to which they have been assigned by the manufacturer. The requirements for these are given in 4.2 to 4.12. The manufacturer shall ensure that the personnel responsible for the classification of laser products and systems have received training to an appropriate level that allows them to understand the full implications of the classification scheme.

- **Modification**

If the modification of a previously classified laser product affects any aspects of the product's performance or intended functions within the scope of this standard, the person or organization performing any such modification is responsible for ensuring the reclassification and relabelling of the laser product.

4.2 Protective housing

4.2.1 General

Each laser product shall have a protective housing which, when in place, prevents human access to laser radiation (including errant laser radiation) in excess of the AEL for Class 1, except when human access is necessary for the performance of the function(s) of the product.

When the classification of a laser product is based on the prevention of human access to a level of energy that is equivalent to Class 4 (for instance, for laser processing machines), the protective housing must withstand exposures under reasonably foreseeable single fault conditions (see 9.1), without human intervention. If the protective housing is of a size that permits human entry, see 4.12.

Maintenance of Class 1, 1M, 2, 2M, or 3R laser products shall not permit human access to levels of laser radiation of Class 3B or Class 4. Maintenance of Class 3B laser products shall not permit human access to levels of laser radiation of Class 4.

4.2.2 Service

Any parts of the housing or enclosure of a laser product (including embedded laser products) that can be removed or displaced for service and which would allow access to laser radiation in excess of the AEL assigned and are not interlocked (see 4.3) shall be secured in such a way that removal or displacement of the parts requires the use of a tool or tools.

4.2.3 Removable laser system

If a laser system can be removed from its protective housing or enclosure and operated without modification, the laser system shall comply with the manufacturing requirements of Clauses 4 and 5 that are appropriate to its class.

4.3 Access panels and safety interlocks

4.3.1 A safety interlock shall be provided for access panels of protective housings when both of the following conditions are met:

a) the access panel is intended to be removed or displaced during maintenance or operation, and

b) the removal of the panel gives access to laser radiation levels designated by "X" in Table 1 below.

Table 1 below indicates (X) the applicability of a safety interlock.

Table 1 – Requirements for safety interlocking

Product class	Accessible emission during or after removal of access panel				
	1, 1M	**2, 2M**	**3R**	**3B**	**4**
1, 1M	–	–	X	X	X
2, 2M	–	–	X	X	X
3R	–	–	–	X	X
3B	–	–	–	X	X
4	–	–	–	X	X

Removal of the panel shall not result in emission through the opening in excess of the AEL for Class 1M or Class 2M, as applicable according to the wavelength.

When a safety interlock is required, the safety interlock shall prevent access to accessible emission levels above the applicable AEL in Table 1 when the panel is removed. Inadvertent resetting of the interlock shall not in itself restore emission values above the applicable AEL in Table 1. These interlocks shall conform to the requirements in the applicable IEC product safety standard (see Clause 1).

NOTE The requirements of 9.1 also apply to interlocks, i.e. interlocks need to be failsafe or redundant.

4.3.2 If a deliberate override mechanism is provided, the manufacturer shall also provide adequate instructions about safe methods of working. It shall not be possible to leave the override in operation when the access panel is returned to its normal position. The interlock shall be clearly associated with a label conforming to 5.9.2. Use of the override shall give rise to a distinct visible or audible warning whenever the laser is energized or capacitor banks are not fully discharged, whether or not the access panel is removed or displaced. Visible warnings shall be clearly visible through protective eyewear specifically designed or specified for the wavelength(s) of the accessible laser radiation.

4.4 Remote interlock connector

Each Class 3B and Class 4 laser system shall have a remote interlock connector. When the terminals of the connector are open-circuited, the accessible radiation shall not exceed the AEL for Class 1M or Class 2M as applicable.

4.5 Manual reset

Each Class 4 laser system shall incorporate a manual reset to enable resumption of accessible Class 4 laser radiation emission after interruption of emission caused by the use of the remote interlock connector or an interruption of longer than 5 s of electrical mains power.

NOTE Manufacturers may include a second interlock connector that does not require active action for starting emission, but it is not required for a product to have two connectors.

4.6 Key control

Each Class 3B and Class 4 laser system shall incorporate a key-operated master control. The key shall be removable and the laser radiation shall not be accessible when the key is removed.

NOTE In this Part 1 the term "key" includes any other control devices, such as magnetic cards, cipher combinations, computer passwords, etc.

4.7 Laser radiation emission warning

4.7.1 Each Class 3R laser system in the wavelength range below 400 nm and above 700 nm and each Class 3B and Class 4 laser system shall satisfy the following.

4.7.2 A warning device shall give an audible or visible signal when the laser system is switched on or if any capacitor banks of a pulsed laser are being charged or have not positively discharged. The warning device shall be fail-safe or redundant. Any visible warning device shall be clearly visible through protective eyewear specifically designed for the wavelength(s) of the emitted laser radiation. The visible warning device(s) shall be located so that viewing does not require exposure to laser radiation in excess of the AEL for Class 1M and 2M.

4.7.3 Each operational control and laser aperture that can be separated by 2 m or more from a radiation warning device shall itself be provided with a radiation warning device. The warning device shall be clearly visible or audible to the person in the vicinity of the operational control or laser aperture.

4.7.4 Where the laser emission may be distributed through more than one output aperture, then a visible warning device shall clearly indicate the output aperture or apertures through which laser emission can occur, in accordance with 4.7.2.

4.8 Beam stop or attenuator

Each Class 3B and Class 4 laser system shall incorporate one or more permanently attached means of attenuation (e. g., beam stop, attenuator, switch). The beam stop or attenuator shall be capable of preventing human access to laser radiation in excess of the AEL for Class 1M or Class 2M as applicable.

4.9 Controls

Each laser product shall have controls located so that adjustment and operation do not require exposure to laser radiation equivalent to Class 3R, Class 3B or Class 4.

4.10 Viewing optics

Any viewing optics, viewport or display screen incorporated in a laser product shall provide sufficient attenuation to prevent human access to laser radiation in excess of the AEL for Class 1M, and, for any shutter or variable attenuator incorporated in the viewing optics, viewport or display screen, a means shall be provided to:

a) prevent human access to laser radiation in excess of the AEL for Class 1M when the shutter is opened or the attenuation varied;

b) prevent opening of the shutter or variation of the attenuator when exposure to laser radiation in excess of the AEL for Class 1M is possible.

4.11 Scanning safeguard

Laser products intended to emit scanned radiation and classified on this basis, shall not, as a result of scan failure or of variation in either scan velocity or amplitude, permit human access to laser radiation in excess of the AEL for the assigned class, unless exposure of people is not reasonably foreseeable during the time interval between failure and when the scanning safeguard reduces emission to levels below the AEL of the class of the product (also see 9.1).

4.12 "Walk-in" access

If a protective housing is equipped with an access panel which provides "walk-in" access then:

a) means shall be provided so that any person inside the housing can prevent activation of a laser hazard that is equivalent to Class 3B or Class 4;

b) a warning device shall be situated so as to provide adequate warning of emission of laser radiation equivalent to Class 3R in the wavelength range below 400 nm and above 700 nm, or of laser radiation equivalent to Class 3B or Class 4 to any person who might be within the housing;

c) where “walk-in” access during operation is intended or reasonably foreseeable, emission of laser radiation that is equivalent to Class 3B or Class 4 while someone is present inside the enclosure of a Class 1, Class 2, or Class 3R product shall be prevented by engineering means.

NOTE Methods to prevent human access to radiation when persons are inside the protective housing may include pressure sensitive floor mats, infrared detectors, etc.

4.13 Environmental conditions

The laser product shall meet the safety requirements defined in this standard under all expected operating conditions appropriate to the intended use of the product. Factors to be considered shall include:

– climatic conditions (e.g. temperature, relative humidity);
– vibration and shock.

If no provisions are made in the product safety standard, the relevant subclauses of IEC 61010-1 shall apply.

NOTE Requirements related to electromagnetic susceptibility are under consideration.

4.14 Protection against other hazards

4.14.1 Non-optical hazards

The requirements of the relevant product safety standard shall be fulfilled during operation and in the event of a single fault for the following:

– electrical hazards;
– excessive temperature;
– spread of fire from the equipment;
– sound and ultrasonics;
– harmful substances;
– explosion.

If no provisions are included in the product safety standard, the relevant subclauses of IEC 61010-1 shall apply.

NOTE Many countries have regulations for the control of harmful substances. Contact the appropriate national agency for these requirements.

4.14.2 Collateral radiation

The protective housing of laser products will normally protect against the hazards of collateral radiation (e.g. ultraviolet, visible, infrared radiation). However, if a concern exists that accessible collateral radiation might be hazardous, the laser MPE values may be applied to conservatively evaluate this hazard.

5 Labelling

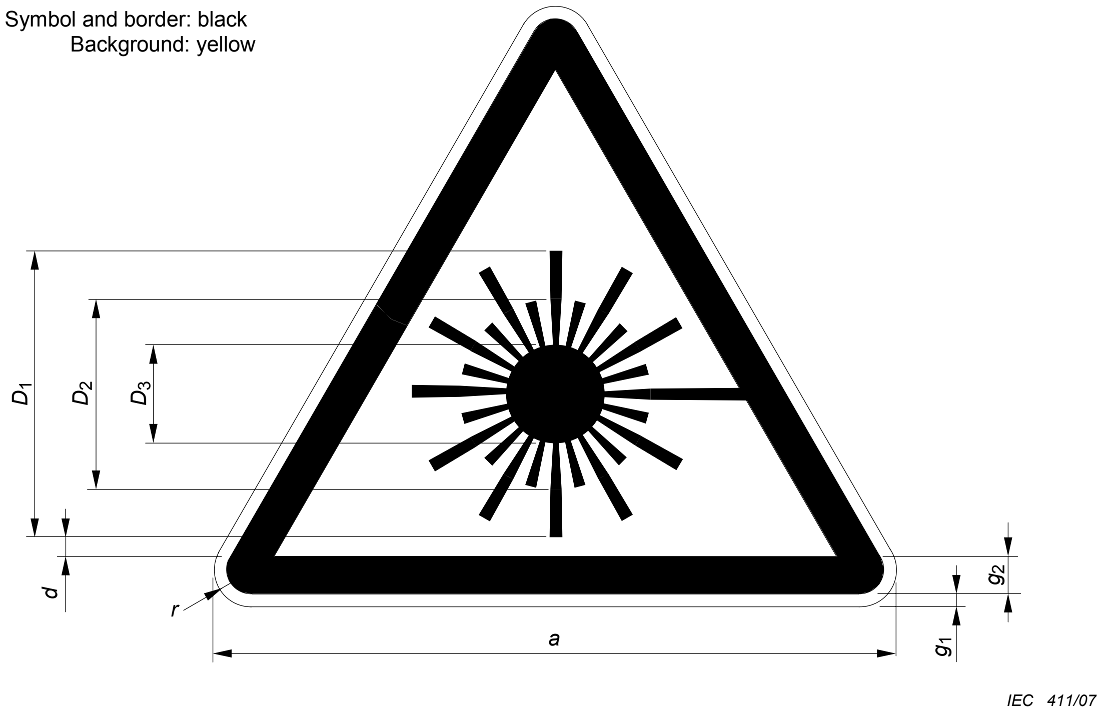
5.1 General

Each laser product shall carry label(s) in accordance with the requirements of the following clauses. The labels shall be durable, permanently affixed, legible, and clearly visible during operation, maintenance or service, according to their purpose. They shall be so positioned that they can be read without the necessity for human exposure to laser radiation in excess of the AEL for Class 1. Text borders and symbols shall be black on a yellow background except for Class 1, where this colour combination need not be used.

The wording of labels shown in Clause 5 is recommended but not mandatory. Other wording that conveys the same meaning may be substituted.

If the size or design of the product makes labelling impractical, the label shall be included with the user information or on the package.

NOTE Direct printing or engraving of equivalent labels on the laser product or panels is acceptable.



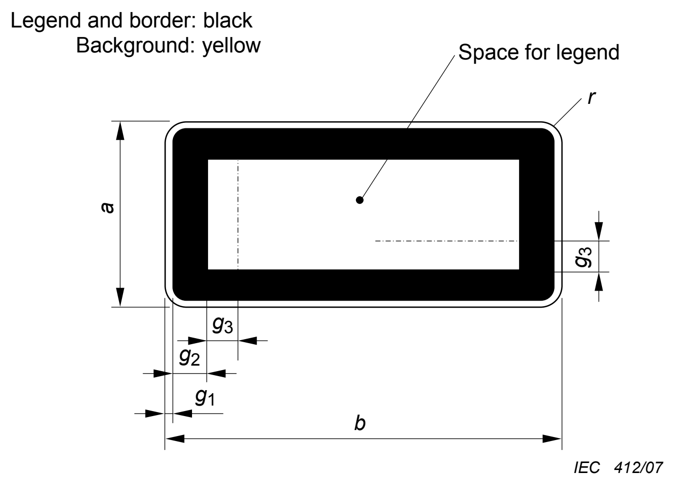
Dimensions in millimetres

a	**g_1**	**g_2**	**r**	**D_1**	**D_2**	**D_3**	**d**
25	0,5	1,5	1,25	10,5	7	3,5	0,5
50	1	3	2,5	21	14	7	1
100	2	6	5	42	28	14	2
150	3	9	7,5	63	42	21	3
200	4	12	10	84	56	28	4
400	8	24	20	168	112	56	8
600	12	36	30	252	168	84	12
The dimensions D_1, D_2, D_3, g_1 and *d* are recommended values.							

NOTE 1 The relationship between the greatest distance *L* from which the label can be understood and the minimum area *A* of the label is given by: $A = L^2/2\,000$, where *A* and *L* are expressed in square metres and metres respectively. This formula applies for distance *L* less than about 50 m.

NOTE 2 These dimensions are recommended values. As long as they are proportional to the values, the symbol and border may be of any legible size as required to suit the size of the laser product.

Figure 1 – Warning label – Hazard symbol



Dimensions in millimetres

$a \times b$	g_1	g_2	g_3	r	Minimum height of lettering
26 × 52	1	4	4	2	Lettering shall be of a size which renders it legible
52 × 105	1,6	5	5	3,2	
84 × 148	2	6	7,5	4	
100 × 250	2,5	8	12,5	5	
140 × 200	2,5	10	10	5	
140 × 250	2,5	10	12,5	5	
140 × 400	3	10	20	6	
200 × 250	3	12	12,5	6	
200 × 400	3	12	20	6	
250 × 400	4	15	25	8	
The dimension g_1 is recommended.					

NOTE 1 The relationship between the greatest distance L from which the label can be understood and the minimum area A of the label is given by: $A = L^2/2\,000$, where A and L are expressed in square metres and metres respectively. This formula applies for distance L less than about 50 m.

NOTE 2 These dimensions are recommended values. The label may be of any size necessary to contain the required lettering and border. The minimum width of each border dimension g_2 and g_3 must be 0,06 times the length of the shorter side of the label.

Figure 2 – Explanatory label

5.2 Class 1 and Class 1M

Except as permitted in Clause 1, each Class 1 laser product shall have affixed an explanatory label (Figure 2) bearing the words:

CLASS 1 LASER PRODUCT

Each Class 1M laser product shall have affixed an explanatory label (Figure 2) bearing the words:

LASER RADIATION
DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 1M LASER PRODUCT

Instead of the above labels, at the discretion of the manufacturer, the same statements may be included in the information for the user.

The type of optical instrument which could result in an increased hazard may be added in parenthesis after the word "instruments" on the Class 1M label. The added wording could in particular be "(BINOCULARS OR TELESCOPES)" for a laser product with a collimated, large-diameter beam, which is classified 1M because it fails condition 1 (see Clause 9), or "(MAGNIFIERS)" for a laser product which is classified 1M because it fails condition 2 (see Clause 9) (highly diverging beam).

Alternatively, the second line of the Class 1M label could read “DO NOT EXPOSE USERS OF BINOCULARS OR TELESCOPES”

If the accessible emission exceeds the AEL of Class 3B as determined with a 3,5 mm diameter aperture placed at the closest point of human access, an additional warning is to be given on a product label and in the information for the user:

SKIN EXPOSURE NEAR APERTURE MAY CAUSE BURNS

NOTE Only applies if condition 2 is used to determine the AEL.

5.3 Class 2 and Class 2M

Each Class 2 laser product shall have affixed a warning label (Figure 1) and an explanatory label (Figure 2) bearing the words:

LASER RADIATION
DO NOT STARE INTO BEAM
CLASS 2 LASER PRODUCT

Each Class 2M laser product shall have affixed a warning label (Figure 1) and an explanatory label (Figure 2) bearing the words:

LASER RADIATION
DO NOT STARE INTO THE BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS
CLASS 2M LASER PRODUCT

The type of optical instrument which could result in an increased hazard may be added in parenthesis after the word "instruments". The added wording could in particular be "(BINOCULARS OR TELESCOPES)" for a laser product with a collimated, large-diameter beam which is classified 2M because it fails condition 1 (see Clause 9), or "(MAGNIFIERS)" for a laser product which is classified 2M because it fails condition 2 (see Clause 9) (highly diverging beam).

Alternatively, the second line of the Class 2M label could read “DO NOT EXPOSE USERS OF BINOCULARS OR TELESCOPES”

If the accessible emission exceeds the AEL of Class 3B as determined with a 3,5 mm diameter aperture placed at the closest point of human access, an additional warning is to be given on a product label and in the information for the user:

SKIN EXPOSURE NEAR APERTURE MAY CAUSE BURNS

NOTE Only applies if condition 2 is used to determine the AEL.

5.4 Class 3R

Each Class 3R laser product shall have affixed a warning label (Figure 1) and an explanatory label (Figure 2) bearing the words:

LASER RADIATION
AVOID DIRECT EYE EXPOSURE
CLASS 3R LASER PRODUCT

NOTE Labels using AVOID EXPOSURE TO BEAM in the second line would also be acceptable.

5.5 Class 3B

Each Class 3B laser product shall have affixed a warning label (Figure 1) and an explanatory label (Figure 2) bearing the words:

LASER RADIATION
AVOID EXPOSURE TO BEAM
CLASS 3B LASER PRODUCT

5.6 Class 4

Each Class 4 laser product shall have affixed a warning label (Figure 1) and an explanatory label (Figure 2) bearing the words:

LASER RADIATION
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION
CLASS 4 LASER PRODUCT

5.7 Aperture label

Each Class 3R, Class 3B and Class 4 laser product shall have affixed a label close to each aperture through which laser radiation in excess of the AEL for Class 1 or Class 2 is emitted. The label(s) shall bear the words:

LASER APERTURE

or

APERTURE FOR LASER RADIATION

or

AVOID EXPOSURE – LASER RADIATION IS
EMITTED FROM THIS APERTURE

5.8 Radiation output and standards information

The name and publication date of the standard to which the product was classified shall be included on the explanatory label or elsewhere in close proximity on the product. Each laser product, except those of Class 1, shall be described on the explanatory label (Figure 2) by a statement of the maximum output of laser radiation (see definition 3.55), the pulse duration (if appropriate) and the emitted wavelength(s). For Class 1 and Class 1M, instead of the labels on the product, the information may be contained in the information for the user.

5.9 Labels for access panels

5.9.1 Labels for panels

Each connection, each panel of a protective housing, and each access panel of a protective enclosure which, when removed or displaced permits human access to laser radiation in excess of the AEL for Class 1, shall have affixed labels bearing the words (for the case of an embedded Class 1M laser, the statement instead may be included in the information for the user):

a)

CAUTION – CLASS 1M LASER RADIATION WHEN OPEN
DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS

if the accessible radiation does not exceed the AEL for Class 1M where the level of radiation is measured according to 9.2 g) and 9.3;

b)

CAUTION – CLASS 2 LASER RADIATION WHEN OPEN
DO NOT STARE INTO THE BEAM

if the accessible radiation does not exceed the AEL for Class 2 where the level of radiation is measured according to 9.2 h) and 9.3;

c)

CAUTION – CLASS 2M LASER RADIATION WHEN OPEN
DO NOT STARE INTO THE BEAM OR VIEW
DIRECTLY WITH OPTICAL INSTRUMENTS

if the accessible radiation does not exceed the AEL for Class 2M where the level of radiation is measured according to 9.2 h) and 9.3;

d)

CAUTION – CLASS 3R LASER RADIATION WHEN OPEN
AVOID DIRECT EYE EXPOSURE

if the accessible radiation does not exceed the AEL for Class 3R;

NOTE Labels using AVOID EXPOSURE TO THE BEAM in the second line would also be acceptable.

e)

CAUTION – CLASS 3B LASER RADIATION WHEN OPEN
AVOID EXPOSURE TO THE BEAM

if the accessible radiation does not exceed the AEL for Class 3B;

f)

CAUTION – CLASS 4 LASER RADIATION WHEN OPEN
AVOID EYE OR SKIN EXPOSURE TO
DIRECT OR SCATTERED RADIATION

if the accessible radiation exceeds the limits for Class 3B.

This information may be provided in more than one adjacent label on the product.

5.9.2 Labels for safety interlocked panels

Appropriate labels shall be clearly associated with each safety interlock which may be readily overridden and which would then permit human access to laser radiation in excess of the AEL of Class 1. Such labels shall be visible prior to and during interlock override and be in close proximity to the opening created by the removal of the protective housing. This label shall bear the words specified in items a) to f) of 5.9.1, as applicable, with the introduction of an additional line, positioned after the first line, with the following words:

AND INTERLOCKS DEFEATED

5.10 Warning for invisible laser radiation

In many cases, the wording prescribed for labels in Clause 5 includes the phrase "LASER RADIATION". If the output of the laser is outside the wavelength range from 400 nm to 700 nm, this shall be modified to read "INVISIBLE LASER RADIATION", or if the output is at wavelengths both inside and outside this wavelength range, to read "VISIBLE AND INVISIBLE LASER RADIATION".

If a product is classified on the basis of the level of visible laser radiation and also emits in excess of the AEL of Class 1 at invisible wavelengths, the label shall include the words "VISIBLE AND INVISIBLE LASER RADIATION" in lieu of "LASER RADIATION".

5.11 Warning for visible laser radiation

The wording "LASER RADIATION" for labels in Clause 5 may be modified to read "LASER LIGHT" if the output of the laser product is in the (visible) wavelength range from 400 nm to 700 nm.

6 Other informational requirements

6.1 Information for the user

Manufacturers of laser products shall provide (or see to the provision of) user instructions or an operation manual that contains all relevant safety information. It remains the responsibility of the manufacturer to provide the safety information indicated below and to decide which additional information is relevant and, therefore, shall be provided.

NOTE The information that is relevant or not relevant depends on the specific product including its intended application and may even be subject to national legislation.

The following information shall be provided:

a) Adequate instructions for proper assembly, maintenance, and safe use, including clear warnings concerning precautions to avoid possible exposure to hazardous laser radiation and description of the classification limitations, if appropriate (see Annex C for a description of the classes and possible limitations).

b) An additional warning for Class 1M and 2M laser products. For diverging beams, this warning shall state that viewing the laser output with certain optical instruments (for example, eye loupes, magnifiers and microscopes) within a distance of 100 mm may pose an eye hazard. For collimated beams, this warning shall state that viewing the laser output with certain optical instruments designed for use at a distance (for example, telescopes and binoculars) may pose an eye hazard.

c) For laser radiation levels above the AEL of Class 1, a description of any radiation pattern(s) emitted from the protective housing during the performance of operation and maintenance procedures. Where applicable, this shall include a statement in appropriate units of:

- wavelength,
- beam divergence,
- pulse duration and repetition rate (or description of irregular pulse pattern),
- maximum power or energy output.

The values shall, where appropriate, include cumulative measurement uncertainties and any expected increase in the measured quantities at any time after manufacture. Duration of pulses resulting from unintentional mode-locking need not be specified; whereas, those conditions associated with the product known to result in unintentional mode-locking shall be specified. For ultrashort pulses, the bandwidth of the radiation (i.e. the wavelength range of emission) shall be specified.

d) For embedded laser products and other incorporated laser products, information to describe the incorporated laser (see item c)). The information shall also include appropriate safety instructions to the user to avoid inadvertent exposure to hazardous laser radiation. This is particularly relevant for embedded laser products that are classified as Class 1, Class 1M, Class 2 or Class 2M but where intrabeam viewing to accessible emission levels in excess of the AELs of these classes is possible during maintenance. In this case the manufacturer shall include a warning that intrabeam viewing of the laser shall be prevented.

e) Where appropriate and relevant, the applicable MPE and NOHD for Class 3B and Class 4 laser products. Since the NOHD greatly depends on the beam delivery system and optical elements placed in the beam, when this is considered as relevant, it is recommended that the different NOHD values are given for the different attachments or beam delivery systems. If there is a variable beam divergence, the NOHD could be given for some selected values of divergence. When an MPE and NOHD value is stated, the assumed exposure duration for the determination of these values shall also be stated. For collimated-beam Class 1M and Class 2M lasers, the extended NOHD (ENOHD) shall be stated, where appropriate and relevant.

NOTE Specific information on the NOHD is typically not required for collimated beams that are to be used indoors. In that case, it is usually sufficient to give only an indication of the extent of the range where the MPE can be exceeded.

f) Where appropriate, information for the selection of eye protection. This shall include the required optical density as well as irradiance or radiation exposure levels that might be incident on the surface of the eye protection equipment, so that resistance levels can be determined.

NOTE Many countries have regulations and standards for personal protective equipment. Contact the appropriate national agency for these requirements.

g) Legible reproductions (colour optional) of all required labels and hazard warnings to be affixed to the laser product or provided with the laser product. The corresponding position of each label affixed to the product shall be indicated or, if provided with the product, a statement that such labels could not be affixed to the product but were supplied with the product and a statement of the form and manner in which they were supplied shall be provided.

h) A clear indication in the manual of all locations of laser apertures through which laser radiation exceeding the Class 1 AEL is emitted.

i) List of controls, adjustments and procedures for operation and maintenance, including the warning "Caution – Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure" (or alternatively, equivalent appropriate warnings).

j) In the case of laser products that do not incorporate the laser energy source necessary for laser emission, a statement of the compatibility requirements for a laser energy source to ensure safety.

6.2 Purchasing and servicing information

Manufacturers of laser products shall provide or cause to be provided the following.

a) In all catalogues, specification sheets and descriptive brochures, the classification of each laser product and any warning shall be stated, including those specified by 6.1 b), if appropriate.

b) To servicing dealers and distributors, and to others upon request, adequate instructions for service adjustments and service procedures for each laser product model, which include:

- clear warnings and precautions to be taken to avoid possible exposure to laser radiation above Class 1 and other hazards;
- a schedule of maintenance necessary to keep the product in compliance;
- a list of those controls and procedures which could be utilized by persons other than the manufacturer or his agents to increase accessible emission levels of radiation;
- a clear description of the location of displaceable portions of the protective housing which could allow access to laser radiation in excess of the accessible limits in Tables 4 to 9;
- protective procedures for service personnel; and
- legible reproductions (colour optional) of required labels and hazard warnings.

7 Additional requirements for specific laser products

7.1 Other parts of the standard series IEC 60825

For specific applications, one or other of the following IEC 60825 series may be applicable (see also Bibliography).

- IEC 60825-2, *Safety of optical fibre communication systems* (provides application notes and examples)

– IEC 60825-4, *Laser guards* (provides design and construction information for laser guards and materials especially where high power lasers are used)
– IEC 60825-12, *Safety of free space optical communication systems used for transmission of information.*

Further information may be found in:

– IEC/TR 60825-3, *Guidance for laser displays and shows*
– IEC/TR 60825-5, *Manufacturer's checklist for IEC 60825-1* (suitable for use in a safety report)
– IEC/TR 60825-8, *Guidelines for the safe use of laser beams on humans*
– IEC/TR 60825-9, *Compilation of maximum permissible exposure to incoherent optical radiation* (broadband sources)
– IEC/TR 60825-10, *Application guidelines and explanatory notes to IEC 60825-1*
– IEC/TR 60825-13, *Measurements for classification of laser products*
– IEC/TR 60825-14, *A user's guide*
– IEC 62471 (CIE S009), *Photobiological safety of lamps and lamp systems*

7.2 Medical laser products

Each medical laser product shall comply with all of the applicable requirements for laser products of its class. In addition, any Class 3B or Class 4 medical laser product is subject to IEC 60601-2-22.

7.3 Laser processing machines

Laser processing machines shall comply with applicable requirements for laser products of their class. In addition, laser processing machines may be subject to ISO/IEC 11553-1.

7.4 Electric toys

Electric toys that are laser products shall comply with applicable requirements for laser products of their class. In addition, these products are subject to IEC 62115.

7.5 Consumer electronic products

Consumer electronic products that are laser products shall comply with applicable requirements for laser products of their class. In addition, these products may be subject to one of the following standards: IEC 60950 (IT equipment), IEC 60065 (AV equipment).

8 Classification

8.1 Introduction

Because of the wide ranges possible for the wavelength, energy content and pulse characteristics of a laser beam, the potential hazards arising in its use vary widely. It is impossible to regard lasers as a single group to which common safety limits can apply. Annex C describes the hazards associated with the classes and possible limitations (e.g. as may arise from optically aided viewing) in more detail.

8.2 Classification responsibilities

It is the responsibility of the manufacturer or his agent to provide correct classification of a laser product (however, see 4.1).

The product shall be classified on the basis of that combination of output power(s) and wavelength(s) of the accessible laser radiation over the full range of capability during operation at any time after manufacture which results in its allocation to the highest appropriate class.

A laser product can only be assigned to a particular class when it has met all of the requirements within this Part 1 for that class, for example engineering controls, labelling and information for the user.

8.3 Classification rules

For the purpose of classification rules, the following ranking of the classes (in increasing order of hazard) shall be used: Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, Class 4.

NOTE For classification of a laser product as Class 1M or 2M, the use of an aperture specified as condition 3 limits the amount of radiation that is collected from large diameter or highly diverging beams. For example, when measured under the applicable conditions, Class 1M and Class 2M products may have higher measured total energy or power than Class 2 or Class 3R. For such laser products, a classification of 1M or 2M is appropriate.

The accessible emission limits (AELs) for Class 1 and 1M, Class 2 and 2M, Class 3R and Class 3B are given in Tables 4 to 9. The values of the correction factors used are given in Table 10 as functions of wavelength, emission duration, number of pulses and angular subtense.

a) Radiation of a single wavelength

   A single wavelength laser product, with a spectral range of the emission line narrow enough so that the AELs do not change, is assigned to a class when the accessible laser radiation, measured under the conditions appropriate to that class, exceeds the AEL of all lower classes but does not exceed that of the class assigned.

b) Radiation of multiple wavelengths

   1) A laser product emitting two or more wavelengths in spectral regions shown as additive in Table 2 is assigned to a class when the sum of the ratios of the accessible laser radiation (measured under the conditions appropriate to that class) to the AELs of those wavelengths is greater than unity for all lower classes but does not exceed unity for the class assigned.

   2) A laser product emitting two or more wavelengths not shown as additive in Table 2 is assigned to a class when the accessible laser radiation, measured under the conditions appropriate to that class, exceeds the AELs of all lower classes for at least one wavelength but does not exceed the AEL for the class assigned for any wavelength.

Table 2 – Additivity of effects on eye and skin of radiation of different spectral regions

Spectral region[a]	UV-C and UV-B 180 nm to 315 nm	UV-A 315 nm to 400 nm	Visible and IR-A 400 nm to 1 400 nm	IR-B and IR-C 1 400 nm to 10^6 nm
UV-C and UV-B 180 nm to 315 nm	**o** **s**			
UV-A 315 nm to 400 nm		**o** **s**	**s**	**o** **s**
Visible and IR-A 400 nm to 1 400 nm		**s**	**o** [b] **s**	**s**
IR-B and IR-C 1 400 nm to 10^6 nm		**o** **s**	**s**	**o** **s**

o Eye
s Skin

a For definitions of spectral regions, see Table D.1.

b Where AELs and ocular MPEs are being evaluated for time bases or exposure durations of 1 s or longer, then the additive photochemical effects (400 nm to 600 nm) and the additive thermal effects (400 nm to 1 400 nm) shall be assessed independently and the most restrictive value used.

c) Radiation from extended sources

The ocular hazard from laser sources in the wavelength range from 400 nm to 1 400 nm is dependent upon the angular subtense of the apparent source α.

NOTE 1 A source is considered an extended source when the angular subtense of the source is greater than α_{min}, where α_{min} = 1,5 mrad. Most laser sources have an angular subtense α less than α_{min}, and appear as an apparent "point source" (small source) when viewed from within the beam (intra-beam viewing). Indeed a circular laser beam cannot be collimated to a divergence less than 1,5 mrad if it is an extended source, thus any laser where a beam divergence in any plane of 1,5 mrad or less is specified cannot be treated as an extended source.

NOTE 2 For retinal thermal hazard evaluation (400 nm to 1 400 nm), the AELs for extended sources vary directly with the angular subtense of the source. For the retinal photochemical hazard evaluation (400 nm to 600 nm), for exposures greater than 1 s, the AELs do not vary directly with the angular subtense of the source. Depending on the emission duration (see 9.3.3b) 1), a limiting angle of acceptance γ_{ph} of 11 mrad or more is used for measurement, and the relation of the limiting acceptance angle γ_{ph} to the angular subtense α of the apparent source can influence the measured value.

NOTE 3 For the default condition where C_6 = 1, a simplified Table 4 is provided for the AEL of Class 1 and 1M.

For sources subtending an angle less than or equal to α_{min}, the AEL and MPE are independent of the angular subtense of the apparent source α.

For classifying laser products at the most restrictive position where condition 1 applies (see 9.3.3), the 7× magnification of the angular subtense α of the apparent source may be applied to determine C_6, i.e. $C_6 = 7 \times \alpha / \alpha_{min}$. The expression ($7 \times \alpha$) shall be limited to α_{max} prior to the calculation of C_6. The 7× value of α shall be used for the determination of T_2 of Table 10.

NOTE For cases where α < 1,5 mrad but $7 \times \alpha$ > 1,5 mrad, the limits for α > 1,5 mrad of Table 5 and 8 apply.

d) Non-uniform retinal image irradiance profile, non-circular and multiple sources

For comparison with the thermal retinal limits, if:

the wavelength range is from 400 nm to 1 400 nm; and

the AEL depends on C_6

then if:

the retinal image does not have a uniform irradiance profile*; or

the retinal image profile consists of multiple points,

* For a Gaussian retinal irradiance profile (as produced by a TEM_{00} beam), the angular subtense can be determined with the d_{63} diameter criterion and an analysis of partial areas is not necessary.

then measurements or evaluations shall be made for each of the following scenarios:

for every single point; and

for various assemblies of points; and

for partial areas.

This is necessary in order to ensure that the AEL is not exceeded for each possible angle α subtended in each scenario. For the evaluation of assemblies of points or for partial areas, the angle of acceptance γ is to be varied between α_{min} and α_{max}, i.e. $\alpha_{min} < \gamma < \alpha_{max}$, to determine the partial accessible emission associated with the respective scenario. For the comparison of these partial accessible emission levels with the respective AEL, the value of α is set equal to γ.

Classification is to be based on the case where the ratio between:

the partial accessible emission within a partial area over the angular subtense α of that area; and

the corresponding AEL

is a maximum.

The angular subtense of a rectangular or linear source is determined by the arithmetic mean value of the two angular dimensions of the source. Any angular dimension that is greater than α_{max} or less than α_{min} shall be limited to α_{max} or α_{min} respectively, prior to calculating the mean.

The photochemical limits (400 nm to 600 nm) do not depend on the angular subtense of the source, and the source is analysed with the limiting angle of acceptance specified in 9.3.3 b). For sources that are larger than the limiting angle of acceptance, the accessible emission has to be determined for the partial apparent source which produces the maximum emission value.

e) Time bases

The following time bases are used in this standard for classification:

1) 0,25 s for Class 2, Class 2M and Class 3R laser radiation in the wavelength range from 400 nm to 700 nm;

2) 100 s for laser radiation of all wavelengths greater than 400 nm except for the cases listed in 1) and 3);

3) 30 000 s for laser radiation of all wavelengths less than or equal to 400 nm and for laser radiation of wavelengths greater than 400 nm where intentional long-term viewing is inherent in the design or function of the laser product.

Every possible emission duration within the time base must be considered when determining the classification of a product. This means that the emission level of a single pulse must be compared to the AEL applicable to the duration of the pulse, etc. It is not sufficient to only average the emission level for the duration of the classification time base, or to merely perform the evaluation for the value of the time base without considering shorter emission durations.

NOTE For a multi wavelength emission laser product with emission in the visible and in the non-visible part of the spectrum, where the emission is assessed as additive (see Table 2), and where the visible part on its own would be classified as Class 2 or 2M or 3R and the non-visible part on its own would be classified as Class 1 or Class 1M, the time base for the assessment of the added emission may be 0,25 s even for the non-visible part.

f) Repetitively pulsed or modulated lasers

The following methods shall be used to determine the class of the laser product to be applied to repetitive pulsed or modulated emissions.

For all wavelengths requirements, 1) and 2) shall be assessed. In addition, for wavelengths from 400 nm to 10^6 nm, requirement 3) shall also be assessed for comparison with thermal limits. Requirement 3) does not need to be assessed for comparison with photochemical limits.

The class (see Tables 4 to 9) is determined by applying the most restrictive of 1), 2) and, where applicable, 3).

1) The exposure from any single pulse within a pulse train shall not exceed the AEL for a single pulse.

2) The average power for a pulse train of emission duration T AEL_T shall not exceed the power corresponding to the AEL for a single pulse of duration T.

NOTE For comparison with AEL_{single} or $AEL_{s.p.train}$, AEL_T should be divided by N and is termed $AEL_{s.p.T}$.

3) a) For constant pulse energy and pulse duration:

The energy per pulse shall not exceed the AEL for a single pulse multiplied by the correction factor C_5.

$$AEL_{s.p.\ train} = AEL_{single} \times C_5$$

where

$AEL_{s.p.\ train}$ is the AEL for a single pulse in the pulse train;

AEL_{single} is the AEL for a single pulse (Tables 4 to 9);

N is the effective number of pulses in the pulse train within the assessed emission duration (when pulses occur within T_i (see Table 3), N is less than the actual number of pulses, see below). The maximum emission duration that needs to be considered for the assessment, for wavelengths between 400 nm and 1 400 nm, is T_2 (see Table 10) or the applicable time basis, whichever is shorter. For wavelengths greater than 1 400 nm, the maximum duration to be considered is 10 s.

$C_5 = N^{-0,25}$

C_5 is only applicable to individual pulse duration shorter than 0,25 s.

If multiple pulses appear within the period of T_i (see Table 3), they are counted as a single pulse to determine N and the energies of the individual pulses are added to be compared to the AEL of T_i.

The energy from any group of pulses (or sub-group of pulses in a train) delivered in any given time shall not exceed the AEL for that time.

Table 3 – Times below which pulse groups are summed

Wavelength nm	T_i s
400 ≤ λ < 1 050	18×10^{-6}
1 050 ≤ λ < 1 400	50×10^{-6}
1 400 ≤ λ < 1 500	10^{-3}
1 500 ≤ λ < 1 800	10
1 800 ≤ λ < 2 600	10^{-3}
2 600 ≤ λ ≤ 10^6	10^{-7}

b) For varying pulse widths or varying pulse durations:

The total-on-time-pulse (TOTP) method shall be used. The AEL is determined by the duration of the TOTP, which is the sum of all pulse durations within the emission duration or T_2, whichever is smaller. Pulses with durations less than T_i are assigned pulse durations of T_i. If two or more pulses occur within a duration of T_i, these pulse groups are assigned pulse durations of T_i. For comparison with the AEL for the corresponding duration, all individual pulse energies are added.

9 Determination of the accessible emission level

9.1 Tests

Tests shall take into account all errors and statistical uncertainties in the measurement process (see IEC 61040) and increases in emission and degradation in radiation safety with age. Specific user requirements may impose additional tests.

Tests during operation shall be used to determine the classification of the product. Tests during operation, maintenance and service shall also be used as appropriate to determine the requirements for safety interlocks, labels and information for the user. The above tests shall be made under each and every reasonably foreseeable single-fault condition. However, if the emission is reduced to a level below the AEL by automatic reduction in a duration within which it is not reasonably foreseeable to have human access, then such faults need not be considered.

NOTE 1 Automatic reduction includes physical limitation of the emission such as component or system failure to a safe condition. It does not include manual reduction or termination of the emission.

NOTE 2 For example, a scanning safeguard may not react fast enough to prevent emission above the AEL during the fault condition; however, this might be acceptable for products where exposure of people is unlikely.

NOTE 3 Acceptable modes of analysis of the probability and risk regarding failures are FMEA (failure mode and effect analysis), etc (see for instance IEC 61508). Probability analysis may be used to assist in determining "reasonably foreseeable single fault conditions".

NOTE 4 Classification is determined during operation, and restrictions on maintenance are then dependent upon the classification of the product.

When assessing the suitability of protective housings for the prevention of human access to a level of energy that is equivalent to Class 4, single fault events for all reasonably foreseeable changes of direction of the beam must be considered. The analysis shall include whether the single fault event will result in sufficient energy to degrade or destroy the protective housing. For example, when during operation or single fault condition, the introduction of robotics or other beam manipulation mechanisms, or the use of optics or workpieces would result in energy being directed onto the surface of the protective housing, one of the following shall occur:

– the single fault shall be eliminated by engineering means; or
– the housing material shall withstand the energy without degradation of its protective properties sufficient to allow a hazardous exposure to laser energy; or
– the fault shall be detected and emission of laser radiation through the protective housing shall be prevented before degradation can occur.

Evaluation times of the protective housing of less than 30 000 s as specified in IEC 60825-4 are not applied for the classification of the product.

NOTE 1 This is because the classification must be considered without human intervention (see 4.2.1) and therefore inspection of the protective housing by the user is not considered.

NOTE 2 Protective housing evaluations that consider human inspection, or intervention, may be used to establish levels of safety, or for the detection of potential degradation of the housing which results from reasonably unforeseeable fault events, or multiple fault events, independent of the product classification.

Equivalent tests or procedures are acceptable.

Optical amplifiers shall be classified using the maximum accessible total output power or energy, which may include maximum rated input power or energy.

NOTE In those cases where there is no clear output power or energy limit, the maximum power or energy added by the amplifier plus the necessary input signal power or energy to achieve that condition should be used.

9.2 Measurement of laser radiation

Measurement of laser radiation levels may be necessary to classify a laser product in accordance with 9.1. Measurements are unnecessary when the physical characteristics and limitations of the laser source place the laser product or laser installation clearly in a particular class. Measurements shall be made under the following conditions and procedures.

a) Conditions and procedures which maximize the accessible emission levels, including start-up, stabilized emission and shut-down of the laser product.

b) With all controls and settings listed in the operation, maintenance and service instructions adjusted in combination to result in the maximum accessible level of radiation. Measurements are also required with the use of accessories that may increase the radiation hazard (for example, collimating optics) which are supplied or offered by the manufacturer for use with the product.

   NOTE This includes any configuration of the product which it is possible to attain without using tools or defeating an interlock, including configurations and settings against which the operation and maintenance instructions contain warnings. For example, when optical elements such as filters, diffusers or lenses in the optical path of the laser beam can be removed without tools, the product must be tested in the configuration which results in the highest hazard level. The instruction by the manufacturer not to remove the optical elements cannot justify classification as a lower class. Classification is based on the engineering design of the product and cannot be based on appropriate behaviour of the user.

c) For a laser product other than a laser system, with the laser coupled to that type of laser energy source which is specified as compatible by the laser product manufacturer and which produces the maximum emission of accessible radiation from the product.

d) At points in space to which human access is possible during operation for measurement of accessible emission levels (for example, if operation may require removal of portions of the protective housing and defeat of safety interlocks, measurements shall be made at points accessible in that product configuration).

e) With the measuring instrument detector so positioned and so oriented with respect to the laser product as to result in the maximum detection of radiation by the instrument.

f) Appropriate provision shall be made to avoid or to eliminate the contribution of collateral radiation to the measurement.

g) Class 1 and 1M

Class 1 is applicable to the wavelength range of 180 nm to 1 mm. Class 1M is applicable to the wavelength range of 302,5 nm to 4 000 nm. For determination of the accessible emission under condition 1, condition 2 and condition 3, see Table 11.

For wavelengths less than 302,5 nm and greater than 4 000 nm, if the accessible emission is less than the AEL of Class 1 for condition 3, then the laser product is assigned to Class 1.

For wavelengths between 302,5 nm and 4 000 nm:

If the radiation level is:

– less than the AEL of Class 1 for condition 1, and condition 2 and condition 3,

then the laser product is assigned to Class 1.

If the accessible emission is:

– greater than the AEL of Class 1 for condition 1 or condition 2, and
– less than the AEL of Class 3B for condition 1 and condition 2, and
– less than the AEL of Class 1 for condition 3,

then the laser product is assigned to Class 1M.

NOTE 1 Typically, the accessible emission of a Class 1M product exceeds the Class 1 AEL for either condition 1 or condition 2. However, it may also be classified as Class 1M when it exceeds that AEL for both condition 1 and condition 2.

NOTE 2 The reason for verifying the AEL of Class 3B is to limit the maximum power passing through an optical instrument.

If the accessible emission exceeds the value given in Table 9 for the AEL of Class 3B as determined with a 3,5 mm diameter aperture placed at the closest point of human access, an additional warning regarding a potential skin hazard is to be given (see 5.2).

NOTE 3 It is possible that a Class 1M laser product with a highly diverging beam can produce high enough irradiance levels near to or in contact with the source (for instance a fibre tip) so that skin injury is possible.

h) Class 2 and 2M

Classes 2 and 2M are applicable to the wavelength range of 400 nm to 700 nm. For determination of the accessible emission under condition 1, condition 2 and condition 3, see Table 11.

If the accessible emission exceeds the limits as required for Class 1 and for Class 1M (see item g)), and is:

– less than the AEL of Class 2 for condition 1, and condition 2 and condition 3,

then the laser product is assigned to Class 2.

If the accessible emission exceeds the limits as required for Class 1 and for Class 1M (see item g)) and is:

– greater than the AEL of Class 2 for condition 1 or condition 2, and
– less than the AEL of Class 3B for condition 1 and condition 2, and
– less than the AEL of Class 2 for condition 3,

then the laser product is assigned to Class 2M.

NOTE 1 The reason for verifying the AEL of Class 3B is to limit the maximum power passing through an optical instrument, and to preclude high irradiance levels near to or in contact with diverging sources which may lead to skin injury.

NOTE 2 Typically, the accessible emission of a Class 2M product exceeds the AEL of Class 2 for either condition 1 or condition 2. However, it may also be classified as Class 2M when it exceeds the AEL of Class 2 for both condition 1 and condition 2.

If the accessible emission exceeds the AEL of Class 3B as determined with a 3,5 mm diameter aperture placed at the closest point of human access, an additional warning regarding a potential skin hazard is to be given (see 5.3).

NOTE 3 It is possible that a Class 2M laser product with a highly diverging beam can produce high enough irradiance levels near to or in contact with the source (for instance, a fibre tip) so that skin injury is possible.

i) Class 3R, 3B

If the level of radiation, as determined according to 9.3, for condition 1, condition 2 and condition 3 is less than or equal to the AEL of Class 3R or Class 3B, the laser product is assigned to Class 3R or Class 3B, respectively. See also Note below first paragraph of 8.3.

j) Class 4

If the level of radiation, as determined according to 9.3, either for condition 1, or condition 2 or condition 3, exceeds the AEL for Class 3B, the product shall be assigned to Class 4.

Table 4 – Accessible emission limits for Class 1 and Class 1M laser products and C_6 = 1 [a, b]

Wave-length λ nm	Emission duration t s										
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to $1{,}8 \times 10^{-5}$	$1{,}8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 0,35	0,35 to 10	10 to 10^2	10^2 to 10^3	10^3 to 3×10^4
180 to 302,5	3×10^{10} W·m^{-2}		30 J·m^{-2}								
302,5 to 315	$2{,}4 \times 10^4$ W		Thermal hazard ($t \le T_1$) $7{,}9 \times 10^{-7}$ C_1 J / Photochemical hazard $7{,}9 \times 10^{-7}$ C_2 J ($t > T_1$)						$7{,}9 \times 10^{-7}$ C_2 J		
315 to 400			$7{,}9 \times 10^{-7}$ C_1 J						$7{,}9 \times 10^{-3}$ J		$7{,}9 \times 10^{-6}$ W
400 to 450	$5{,}8 \times 10^{-9}$ J	$1{,}0\ t^{0{,}75}$ J	2×10^{-7} J		$7 \times 10^{-4}\ t^{0{,}75}$ J				$3{,}9 \times 10^{-3}$ J	$3{,}9 \times 10^{-5}$ C W	
450 to 500									$3{,}9 \times 10^{-3}$ C_3 J and [c] $3{,}9 \times 10^{-4}$ W		
500 to 700									$3{,}9 \times 10^{-4}$ W		
700 to 1 050	$5{,}8 \times 10^{-9}$ C_4 J	$1{,}0\ t^{0{,}75}$ C_4 J	2×10^{-7} C_4 J		$7 \times 10^{-4}\ t^{0{,}75}$ C_4 J				$3{,}9 \times 10^{-4}$ C_4 C_7 W		
1 050 to 1 400	$5{,}8 \times 10^{-8}$ C_7 J	$10{,}4\ t^{0{,}75}$ C_7 J	2×10^{-6} C_7 J			$3{,}5 \times 10^{-3}\ t^{0{,}75}$ C_7 J					
1 400 to 1 500	8×10^5 W		8×10^{-4} J				$4{,}4 \times 10^{-3}\ t^{0{,}25}$ J	$10^{-2}\ t$ J	$1{,}0 \times 10^{-2}$ W		
1 500 to 1 800	8×10^6 W		8×10^{-3} J					$1{,}8 \times 10^{-2}\ t^{0{,}75}$ J			
1 800 to 2 600	8×10^5 W		8×10^{-4} J				$4{,}4 \times 10^{-3}\ t^{0{,}25}$ J	$10^{-2}\ t$ J			
2 600 to 4 000	8×10^4 W		8×10^{-5} J	$4{,}4 \times 10^{-3}\ t^{0{,}25}$ J							
4 000 to 10^6	10^{11} W·m^{-2}		100 J·m^{-2}	$5\ 600\ t^{0{,}25}$ J·m^{-2}					1 000 W·m^{-2}		

NOTE Laser products that meet the requirements for classification as Class 1 by satisfying measurement conditions 1 and 2 may be hazardous when used with viewing optics having greater than ×7 magnification or objective diameters greater than those specified in Table 11.

[a] For correction factors and units, see Table 10

[b] The AELs for emission durations less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

[c] In the wavelength range between 450 nm and 500 nm, dual limits apply and a product's emission must not exceed either limit applicable to the class assigned.

Table 5 – Accessible emission limits for Class 1 laser products in the wavelength range from 400 nm to 1 400 nm (retinal hazard region): extended sources [a, b, c, d, e]

Wave-length λ nm	Emission duration t s							
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to $1,8 \times 10^{-5}$	$1,8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 10	10 to 10^2	10^2 to 10^4	10^4 to 3×10^4
400 to 700	$5,8 \times 10^{-9}\ C_6$ J	$1,0\ t^{0,75}\ C_6$ J	$2 \times 10^{-7}\ C_6$ J	$7 \times 10^{-4}\ t^{0,75}\ C_6$ J		400 nm to 600 nm – Retinal photochemical hazard [d]		
						$3,9 \times 10^{-3}\ C_3$ J using γ_{ph} = 11 mrad	$3,9 \times 10^{-5}\ C_3$ W using $\gamma_{ph} = 1,1\ t^{0,5}$ mrad	$3,9 \times 10^{-5}\ C_3$ W using γ_{ph} = 110 mrad
						AND [c]		
						400 nm to 700 nm – Retinal thermal hazard		
						($t \le T_2$) $7 \times 10^{-4}\ t^{0,75}\ C_6$ J / $7 \times 10^{-4}\ C_6\ T_2^{-0,25}$ W ($t > T_2$)		
700 to 1 050	$5,8 \times 10^{-9}\ C_4\ C_6$ J	$1,0\ t^{0,75}\ C_4\ C_6$ J	$2 \times 10^{-7} C_4\ C_6$ J	$7 \times 10^{-4}\ t^{0,75}\ C_4\ C_6$ J		($t \le T_2$) $7 \times 10^{-4}\ t^{0,75}\ C_4\ C_6\ C_7$ J / $7 \times 10^{-4}\ C_4\ C_6\ C_7\ T_2^{-0,25}$ W ($t > T_2$)		
1 050 to 1 400	$5,8 \times 10^{-8}\ C_6\ C_7$ J	$10,4\ t^{0,75}\ C_6\ C_7$ J	$2 \times 10^{-6}\ C_6\ C_7$ J		$3,5 \times 10^{-3}\ t^{0,75}\ C_6\ C_7$ J			

NOTE Laser products that meet the requirements for classification as Class 1 by satisfying measurement conditions 1 and 2 may be hazardous when used with viewing optics having greater than ×7 magnification or objective diameters greater than those specified in Table 11.

a For correction factors and units, see Table 10.

b The AELs for emission duration less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

c In the wavelength range between 400 nm and 600 nm, dual limits apply and a product's emission shall not exceed either limit applicable to the class assigned.

d The angle γ_{ph} is the limiting measurement angle of acceptance.

e If exposure times between 1 s and 10 s are used, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of $3,9 \times 10^{-3}\ C_3$ J is extended to 1 s.

Table 6 – Accessible emission limits for Class 2 and Class 2M laser products

Wavelength λ nm	**Emission duration *t*** s	**Class 2 AEL**
400 to 700	$t < 0{,}25$	Same as Class 1 AEL
	$t \geq 0{,}25$	$C_6 \times 10^{-3}$ W [a]
NOTE Laser products that meet the requirements for classification as Class 2 by satisfying measurement conditions 1 and 2 may be hazardous when used with viewing optics having greater than ×7 magnification or aperture diameters greater than those specified in Table 11.		
[a] For correction factor and units, see Table 10.		

Table 7 – Accessible emission limits for Class 3R laser products and C_6 = 1 [a, b, c]

Wavelength λ nm	Emission duration t s									
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to $1,8 \times 10^{-5}$	$1,8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 0,35	0,35 to 10	10 to 10^3	10^3 to 3×10^4
180 to 302,5	$1,5 \times 10^{11}$ W·m^{-2}		150 J·m^{-2}							
302,5 to 315	$1,2 \times 10^5$ W		Thermal hazard 4×10^{-6} C_1 J ($t \leq T_1$)[c] / Photochemical hazard $4,0 \times 10^{-6}$ C_2 J ($t > T_1$)[c]						$4,0 \times 10^{-6}$ C_2 J	
315 to 400			$4,0 \times 10^{-6}$ C_1 J						$4,0 \times 10^{-2}$ J	$4,0 \times 10^{-5}$ W
400 to 700	$2,9 \times 10^{-8}$ J	$5,0\ t^{0,75}$ J	1×10^{-6} J		(t < 0,25 s) $3,5 \times 10^{-3}\ t^{0,75}$ J / $5,0 \times 10^{-3}$ W ($t \geq 0,25$ s)			$5,0 \times 10^{-3}$ W		
700 to 1 050	$2,9 \times 10^{-8}$ C_4 J	$5,0\ t^{0,75}$ C_4 J	1×10^{-6} C_4 J		$3,5 \times 10^{-3}\ t^{0,75}$ C_4 J				$2,0 \times 10^{-3}$ C_4 C_7 W	
1 050 to 1 400	$2,9 \times 10^{-7}$ C_7 J	$52\ t^{0,75}$ C_7 J	1×10^{-5} C_7 J			$1,8 \times 10^{-2}\ t^{0,75}$ C_7 J				
1 400 to 1 500	4×10^6 W		4×10^{-3} J			$2,2 \times 10^{-2}\ t^{0,25}$ J		$5 \times 10^{-2}\ t$ J	$5,0 \times 10^{-2}$ W	
1 500 to 1 800	4×10^7 W		4×10^{-2} J					$9 \times 10^{-2}\ t^{0,75}$ J		
1 800 to 2 600	4×10^6 W		4×10^{-3} J			$2,2 \times 10^{-2}\ t^{0,25}$ J		$5 \times 10^{-2}\ t$ J		
2 600 to 4 000	4×10^5 W		4×10^{-4} J	$2,2 \times 10^{-2}\ t^{0,25}$ J						
4 000 to 10^6	5×10^{11} W·m^{-2}		500 J·m^{-2}	$2,8 \times 10^4\ t^{0,25}$ J·m^{-2}					5 000 W·m^{-2}	

a For correction factors and units, see Table 10.

b The AELs for emission durations less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

c For repetitively pulsed UV lasers neither limit should be exceeded.

Table 8 – Accessible emission limits for Class 3R laser products in the wavelength range from 400 nm to 1 400 nm (retinal hazard region): extended sources [a, b]

Wave-length λ nm	Emission duration t s									
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to $1,8 \times 10^{-5}$	$1,8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 0,35	0,35 to 10	10 to 10^3	10^3 to 3×10^4
400 to 700	$2,9 \times 10^{-8}$ C_6 J	$5,0\ t^{0,75}$ C_6 J	$1 \times 10^{-6}\ C_6$ J		$3,5 \times 10^{-3}\ t^{0,75}\ C_6$ J (t < 0,25 s) / $5,0 \times 10^{-3}\ C_6$ W ($t \geq 0,25$ s)			$5,0 \times 10^{-3}\ C_6$ W		
700 to 1 050	$2,9 \times 10^{-8}$ $C_4\ C_6$ J	$5,0\ t^{0,75}$ $C_4\ C_6$ J	$1 \times 10^{-6}\ C_4\ C_6$ J		$3,5 \times 10^{-3}\ t^{0,75}\ C_4\ C_6$ J				$3,5 \times 10^{-3}\ t^{0,75}\ C_4\ C_6\ C_7$ J ($t \leq T_2$) / $3,5 \times 10^{-3}\ C_4\ C_6\ C_7\ T_2^{-0,25}$ W ($t > T_2$)	
1 050 to 1 400	$2,9 \times 10^{-7}$ $C_6\ C_7$ J	$52\ t^{0,75}$ $C_6\ C_7$ J	$1 \times 10^{-5}\ C_6\ C_7$ J			$1,8 \times 10^{-2}\ t^{0,75}\ C_6\ C_7$ J			$5,0 \times 10^{-2}$ W	

a For correction factors and units, see Table 10.

b The AELs for emission durations less than 10^{-13} s are set to be equal to the equivalent power or irradiance values of the AEL at 10^{-13} s.

Table 9 – Accessible emission limits for Class 3B laser products

Wave-length λ nm	Emission duration *t* s		
	<10^{-9}	**10^{-9} to 0,25**	**0,25 to 3 × 10^4**
180 to 302,5	3,8 × 10^5 W	3,8 × 10^{-4} J	1,5 × 10^{-3} W
302,5 to 315	1,25 × 10^4 C_2 W	1,25 × 10^{-5} C_2 J	5 × 10^{-5} C_2 W
315 to 400	1,25 × 10^8 W	0,125 J	0,5 W
400 to 700	3 × 10^7 W	0,03 J for t< 0,06 s 0,5 W for $t \geq$ 0,06 s	0,5 W
700 to 1 050	3 × 10^7 C_4 W	0,03 C_4 J for t < 0,06 C_4 s 0,5 W for $t \geq$ 0,06 C_4 s	0,5 W
1 050 to 1 400	1,5 × 10^8 W	0,15 J	0,5 W
1 400 to 10^6	1,25 × 10^8 W	0,125 J	0,5 W
For correction factors and units, see Table 10.			

The correction factors C_1 to C_7 and breakpoints T_1 and T_2 used in Tables 4 to 9 are defined in the following expressions (see Table 10).

Table 10 – Correction factors and breakpoints for use in AEL and MPE evaluations

Parameter	Spectral region nm
$C_1 = 5,6 \times 10^3\ t^{0,25}$	180 to 400
$T_1 = 10^{0,8(\lambda - 295)} \times 10^{-15}$ s	302,5 to 315
$C_2 = 30$	180 to 302,5
$C_2 = 10^{0,2(\lambda - 295)}$	302,5 to 315
$T_2 = 10 \times 10^{[(\alpha - \alpha_{min})/98,5]}$ s	400 to 1 400
$T_2 = 10$ s for $\alpha < 1,5$ mrad	400 to 1 400
$T_2 = 100$ s for $\alpha > 100$ mrad	400 to 1 400
$C_3 = 1,0$	400 to 450
$C_3 = 10^{0,02(\lambda - 450)}$	450 to 600
$C_4 = 10^{0,002(\lambda - 700)}$	700 to 1 050
$C_4 = 5$	1 050 to 1 400
$C_5 = N^{-1/4}$ [a]	400 to 10^6
$C_6 = 1$	180 to 400 and 1 400 to 10^6
$C_6 = 1$ for $\alpha \le \alpha_{min}$ [b]	400 to 1 400
$C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \le \alpha_{max}$ [b]	400 to 1 400
$C_6 = \alpha_{max}/\alpha_{min} = 66,7$ for $\alpha > \alpha_{max}$ [b,c]	400 to 1 400
$C_7 = 1$	700 to 1 150
$C_7 = 10^{0,018(\lambda - 1\,150)}$	1 150 to 1 200
$C_7 = 8$	1 200 to 1 400

$\alpha_{min} = 1,5$ mrad
$\alpha_{max} = 100$ mrad

N is the number of pulses contained within the applicable duration (8.3 f) and Clause A.3).

NOTE 1 There is only limited evidence about effects for exposures of less than 10^{-9} s for wavelengths less than 400 nm and greater than 1 400 nm. The AELs for these emission durations and wavelengths have been derived by calculating the equivalent radiant power or irradiance from the radiant power or radiant exposure applying at 10^{-9} s for wavelengths less than 400 nm and greater than 1 400 nm.

NOTE 2 See Table 11 for aperture stops and Table A.4 for limiting apertures.

NOTE 3 In the formulae in Tables 4 to 9 and in these notes, the wavelength must be expressed in nanometres, the emission duration *t* must be expressed in seconds and α must be expressed in milliradians.

NOTE 4 For emission durations which fall at the cell border values (for instance 10 s) in Tables 4 to 9, the lower limit applies. Where the symbol "<" is used, this means less than or equal to.

a C_5 is only applicable to pulse durations shorter than 0,25 s.

b C_6 is only applicable to pulsed lasers and to CW lasers for thermal retinal limits.

c The maximum limiting angle of acceptance γ_{th} shall be equal to α_{max} (but see 8.4 d)).

9.3 Measurement geometry

9.3.1 General

Three measurement conditions are specified for the determination of the accessible emission. Condition 1 and 2 are applied for wavelengths where optically aided viewing may increase the hazard. Condition 1 is intended to apply to collimated beams where telescopes and binoculars may increase the hazard, and condition 2 is intended to apply to sources with a highly diverging output where the use of microscopes, hand magnifiers and eye loupes may increase the hazard. Condition 3 applies to the unaided eye. For power and energy measurement of scanned laser radiation, condition 3 shall be used.

The most restrictive of the applicable measurement conditions shall be applied. If the most restrictive condition is not obvious, each applicable condition shall be evaluated.

The following two evaluation schemes are specified.

a) A simplified (default) method, where the test for classification is performed at a fixed distance relative to a reference point which usually can be easily identified. For this simplified evaluation, it is not necessary to determine the angular subtense of the apparent source, as C_6 (see Table 10) is set equal to unity.

b) For radiation with wavelengths in the retinal hazard region of 400 nm to 1 400 nm, when the AEL is increased by a parameter C_6 with values greater than 1 for extended sources, it is necessary to assess the class of the product (i.e. to compare the accessible emission value with the corresponding AEL) at the most restrictive position in the beam. This second method is more complicated than the default evaluation in a) above, but, for extended sources, it can allow higher accessible emission values.

   NOTE The most restrictive position is in many cases not at a distance of 100 mm to the reference point used for the basic evaluation, but further away. Determination of the angular subtense of the apparent source at a distance of 100 mm from the reference point would in those cases result in an AEL which exceeds the AEL determined at the most restrictive position.

If the simplified (default) evaluation results in the desired classification, there is no need to perform the complete evaluation for extended sources (see 9.3.2), even though the actual source might be extended and the actual factor C_6 might be greater than 1 and the most restrictive position is different from the position as given in Table 11.

NOTE If the source is a bare laser diode or if it emits a well collimated laser beam, the simplified (default) evaluation is usually the appropriate one, i.e. produces equivalent results to the extended source method as described in 9.3.3.

9.3.2 Default (simplified) evaluation

The default, simplified measurement distances in Table 11 are applicable:

– for sources with wavelengths less than 400 nm and larger than 1 400 nm, or

– if the factor C_6 is set equal to 1, or

– for the photochemical retinal limit for time base values longer than 100 s when the measurement angle of acceptance is not restricted (i.e. shall be at least as large as the angular subtense of the apparent source),

– for other limits that are neither photochemical nor thermal (i.e. do not depend on C_6) retinal limits (such as the AEL of Class 3B).

The distances specified in Table 11 are defined as distance from the reference points listed in Table 12.

Table 11 – Measurement aperture diameters and measurement distances for the default (simplified) evaluation

	Condition 1 *applied to collimated beam where e.g. telescope or binoculars may increase the hazard*		**Condition 2** *applied to diverging beam where e.g. magnifying glasses, microscopes may increase the hazard*		**Condition 3** *applied to determine irradiation relevant for the unaided eye and for scanning beams*	
Wavelength nm	**Aperture stop** mm	**Distance** mm	**Aperture stop** mm	**Distance** mm	**Aperture stop/ limiting aperture** mm	**Distance** mm
< 302,5	–	–	–	–	1	0
≥ 302,5 to 400	25	2 000	7	70	1	100
≥ 400 to 1 400	50	2 000	7	70	7	100
≥ 1 400 to 4 000	7 × condition 3	2 000	7	70	1 for $t \leq 0{,}35$ s 1,5 $t^{3/8}$ for 0,35 s < t < 10 s 3,5 for $t \geq 10$ s (t in s)	100
≥ 4 000 to 10^5	–	–	–	–	1 for $t \leq 0{,}35$ s 1,5 $t^{3/8}$ for 0,35 s < t < 10 s 3,5 for $t \geq 10$ s (t in s)	0
≥ 10^5 to 10^6	–	–	–	–	11	0

NOTE The descriptions below the “Condition” headings are typical cases for information only and are not intended to be exclusive.

Table 12 – Reference points

Type of product	**Reference point**
Semiconductor emitters (LEDs, laser diodes, superluminescent diodes)	Physical location of the emitting chip
Scanned emission (including scanned line lasers)	Scanning vertex (pivot point of the scanning beam)
Line laser	Focal point of the line (vertex of the fan angle)
Output of fibre	Fibre tip
Totally diffused sources	Surface of diffuser
Others	Beam waist

NOTE If the reference point is located inside of the protective housing (i.e. is not accessible) at a distance from the closest point of human access further than the measurement distance specified in Table 11, the measurement must be carried out at the closest point of human access.

9.3.3 Evaluation condition for extended sources

For wavelengths in the retinal hazard range (400 nm to 1 400 nm), the accessible emission and the AEL for classification shall be determined at the most restrictive position:

– when a value of C_6 larger than 1 is considered for determination of the AEL, or

– when a limited angle of acceptance is considered for the determination of the accessible emission for comparison with photochemical retinal limits.

The accessible emission and the AEL (C_6) are determined together (i.e. they are paired values) at different positions within the beam, and the values obtained for the most restrictive position are used to determine the class of the product. This implies that the accessible emission (that is compared to the AEL) and the AEL are determined for the same position within the beam, i.e. the angular subtense of the apparent source α (and therefore C_6) is determined at the position of the aperture stop that is used to determine the accessible emission.

NOTE 1 In the case where the divergence of the laser beam is less than 1,5 mrad, then the angular subtense of the apparent source α is α_{min} and the determination of the accessible emission may be performed under the conditions specified in 9.3.1.

NOTE 2 If the source is diffuse, for instance a laser beam incident on a transmissive diffuser plate, then the diffuser can be considered as the location of the apparent source and the emission pattern at the diffuser can be used to determine the angular subtense of the apparent source (see 8.3 d)) for the evaluation method of non-uniform patterns).

NOTE 3 In some more complex arrangements with multiple sources or multiple focal points, it may be more appropriate to use a more elaborate technique, such as ray tracing.

a) Aperture diameters

For condition 1 and condition 3, for the determination of the accessible emission, as well as the angular subtense of the apparent source (both of which are to be determined at the most restrictive position in the beam), the aperture diameters as specified in Table 11 shall be used (see Figures 3 and 4).

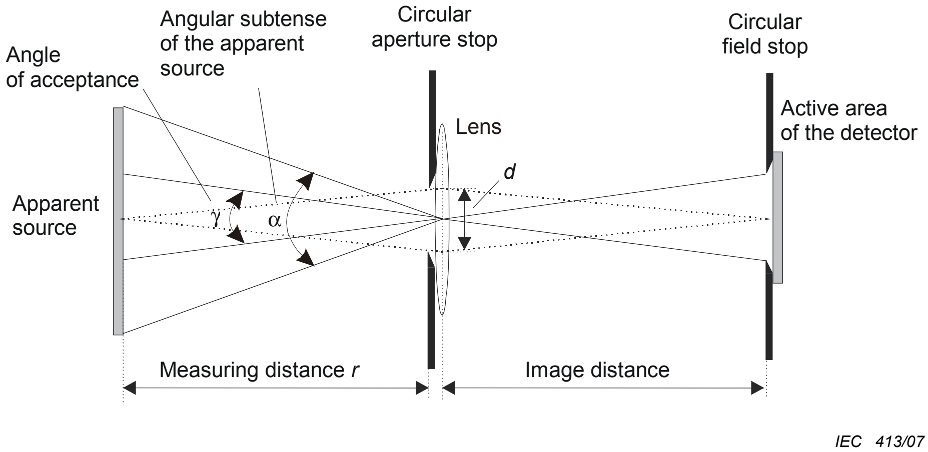
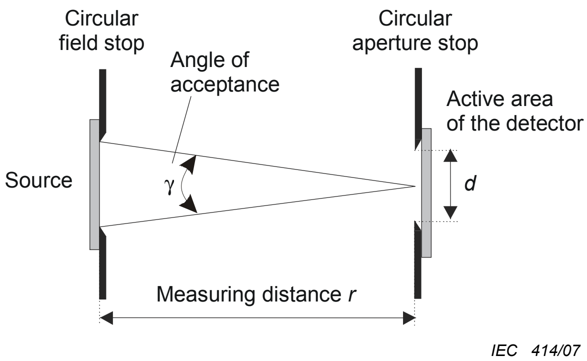


Figure 3 – Measurement set-up to limit angle of acceptance by imaging the apparent source onto the plane of the field stop



NOTE When the apparent source is not accessible, this set-up is not appropriate.

Figure 4 – Measurement set-up to limit angle of acceptance by placing a circular aperture or a mask (serving as field stop) close to the apparent source

For condition 2, for determination of the accessible emission as well as of the angular subtense of the apparent source, a positive lens L1 with a focal length of 35 mm and an aperture with a diameter of 7 mm is to be placed (see Figure 5) at a distance of 35 mm from the reference point as given in Table 12. The aperture stop for the determination of the accessible emission as well as for the determination of the angular subtense of the apparent source is to be placed at a distance of 100 mm from the lens L1 and the diameter of this aperture stop shall be 3,5 mm.

NOTE The lens L1 is to represent a magnifying glass with a magnification of × 7. When diverging sources are placed at the focal point of the lens, the radiation is collimated, thereby affecting both the accessible emission as determined with the aperture stop as well as the angular subtense of the apparent source. Since all distances are fixed, for condition 2 it is not necessary to identify the most restrictive position.

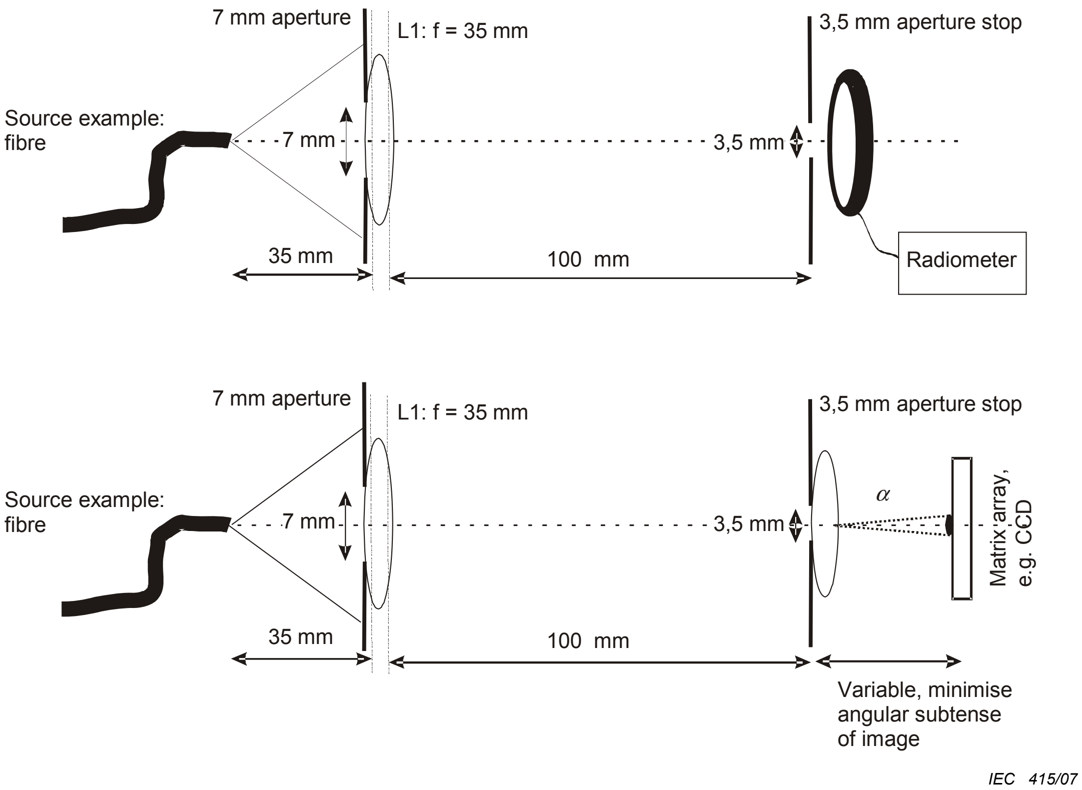


Figure 5 – Experimental set-up for the determination of the accessible emission (above) and the angular subtense of the apparent source (below) for condition 2 when an extended source is to be considered (i.e. not using the default, simplified evaluation)

b) Angle of acceptance

The angle of acceptance is determined by the ratio of the diameter of the field stop and the lens to field stop distance (image distance) (Figure 3), or by the ratio of the diameter of the field stop and the source-detector distance (Figure 4). Losses due to the lens have to be taken into account.

For condition 2 and condition 3, the angle of acceptance for the determination of the accessible emission level shall be as stated in 1) and 2) below. For condition 1, the angle of acceptance is determined by dividing the values given in 1) and 2) by a factor 7.

1) Photochemical retinal limits

For measurements of sources to be evaluated against the photochemical limits (400 nm to 600 nm), the limiting angle of acceptance γ_{ph} is given in Table 13.

Table 13 – Limiting angle of acceptance γ_{ph}

Emission duration s	**γ_{ph} for condition 1** mrad	**γ_{ph} for condition 2 and condition 3** mrad
$10 < t \leq 100$	1,57	11
$100 < t \leq 10^4$	$0,16 \times t^{0,5}$	$1,1\ t^{0,5}$
$10^4 < t \leq 3 \times 10^4$	16	110

If the angular subtense of the source α is larger than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance should not be larger than the values specified for γ_{ph}. If the angular subtense of the source α is smaller than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance shall fully encompass the source under consideration but need not, otherwise, be well defined (i.e. the angle of acceptance need not be restricted to γ_{ph}).

NOTE For measurements of single sources where $\alpha < \gamma_{ph}$, it will not be necessary to measure with a specific, well-defined angle of acceptance. To obtain a well-defined angle of acceptance, the angle of acceptance can be defined by either imaging the source onto a field stop or by masking off the source – see Figures 3 and 4 respectively.

2) All other retinal limits

For measurement of radiation to be compared to retinal limits other than the photochemical limits, the angle of acceptance shall fully encompass the source under consideration (i.e. the angle of acceptance shall be at least as large as the angular subtense of the source α). However, if $\alpha > \alpha_{max}$ the limiting angle of acceptance is α_{max} (100 mrad). Within the wavelength range of 400 nm to 1 400 nm, for the evaluation of an apparent source which consists of multiple points, the angle of acceptance has to be varied in the range of $\alpha_{min} \leq \gamma \leq \alpha_{max}$ (see 8.3 d)).

Annex A
(informative)

Maximum permissible exposure values

A.1 General remarks

Accessible emission limits (AELs) are generally derived from the maximum permissible exposures (MPEs). MPEs have been included in this annex to provide manufacturers with additional information that can assist in evaluating the safety aspects related to the intended use of their product (such as the determination of the NOHD).

NOTE Simplified calculations may significantly underestimate the NOHD. For example, when the laser aperture is inside of a large Raleigh range, when there is an external beam waist, or when the beam profile is such that the power that passes through an aperture is underestimated when a Gaussian beam profile is assumed. In such cases it is usually advantageous to determine the NOHD by measurements.

Maximum permissible exposure values as contained in this document are adopted from exposure limit values published by International Commission on Non-Ionizing Radiation Protection. MPE values are set below known hazard levels and are based on the best available information from experimental studies. The MPE values should be used as guides in the control of exposures and should not be regarded as precisely defined dividing lines between safe and dangerous levels. In any case, exposure to laser radiation should be as low as possible.

Exposures from several wavelengths should be assumed to have an additive effect on a proportional basis of spectral effectiveness according to the MPEs of Tables A.1, A.2 and A.3 provided that the spectral regions are shown as additive by the symbols (o) for ocular and (s) for skin exposure in the matrix of Table 2. Where the wavelengths radiated are not shown as additive, the hazards should be assessed separately.

Table A.1 – Maximum permissible exposure (MPE) for $C_6 = 1$ at the cornea for exposure to laser radiation [a, b]

Wave-length λ nm	Exposure time t s									
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to $1,8 \times 10^{-5}$	$1,8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 10	10 to 10^2	10^2 to 10^3	10^3 to 3×10^4
180 to 302,5	3×10^{10} W·m^{-2}		30 J·m^{-2}							
302,5 to 315			Thermal hazard [d] ($t \leq T_1$) C_1 J·m^{-2}				Photochemical hazard [d] ($t > T_1$) C_2 J·m^{-2}	C_2 J·m^{-2}		
315 to 400			C_1 J·m^{-2}					10^4 J m^{-2}		
400 to 450	$1,5 \times 10^{-4}$ J·m^{-2}	$2,7 \times 10^4\ t^{0,75}$ J·m^{-2}	5×10^{-3} J·m^{-2}		$18\ t^{0,75}$ J·m^{-2}			100 J·m^{-2}	C_3 W·m^{-2}	
450 to 500								100 C_3 J·m^{-2} and [c] 10 W·m^{-2}		
500 to 700								10 W·m^{-2}		
700 to 1 050	$1,5 \times 10^{-4}\ C_4$ J·m^{-2}	$2,7 \times 10^4\ t^{0,75}\ C_4$ J·m^{-2}	$5 \times 10^{-3}\ C_4$ J·m^{-2}		$18\ t^{0,75}\ C_4$ J·m^{-2}			10 C_4 C_7 W·m^{-2}		
1 050 to 1 400	$1,5 \times 10^{-3}\ C_7$ J·m^{-2}	$2,7 \times 10^5\ t^{0,75}\ C_7$ J·m^{-2}	$5 \times 10^{-2}\ C_7$ J·m^{-2}			$90\ t^{0,75}\ C_7$ J·m^{-2}				
1 400 to 1 500	10^{12} W·m^{-2}		10^3 J·m^{-2}				$5\,600\ t^{0,25}$ J·m^{-2}	1 000 W·m^{-2}		
1 500 to 1 800	10^{13} W·m^{-2}		10^4 J·m^{-2}							
1 800 to 2 600	10^{12} W·m^{-2}		10^3 J·m^{-2}				$5\,600\ t^{0,25}$ J·m^{-2}			
2 600 to 10^6	10^{11} W·m^{-2}		100 J·m^{-2}	$5\,600\ t^{0,25}$ J·m^{-2}						

[a] For correction factors and units, see Table 10

[b] The MPEs for exposure durations below 10^{-9} s and for wavelengths less than 400 nm and greater than 1 400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

[c] In the wavelength range between 450 nm and 500 nm, dual limits apply and the exposure must not exceed either limit applicable.

[d] For repetitively pulsed UV lasers neither limit should be exceeded

Table A.2 – Maximum permissible exposure (MPE) at the cornea for exposure to laser radiation from extended sources in the wavelength range from 400 nm to 1 400 nm (retinal hazard region)

Wavelength λ nm	Exposure time t s: 10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to $1,8 \times 10^{-5}$	$1,8 \times 10^{-5}$ to 5×10^{-5}	5×10^{-5} to 10	10 to 10^2	10^2 to 10^4	10^4 to 3×10^4
400 to 700	$1,5 \times 10^{-4}\ C_6$ J·m^{-2}	$2,7 \times 10^4\ t^{0,75}\ C_6$ J·m^{-2}	$5 \times 10^{-3}\ C_6$ J·m^{-2}	$18\ t^{0,75}\ C_6$ J·m^{-2}		400 nm to 600 nm – Retinal photochemical hazard [a]		
						$100\ C_3$ J·m^{-2} using γ_{ph} = 11 mrad	$1\ C_3$ W·m^{-2} using $\gamma_{ph} = 1,1\ t^{0,5}$ mrad	$1\ C_3$ W·m^{-2} using γ_{ph} = 110 mrad
						AND [b]		
						400 nm to 700 nm – Retinal thermal hazard		
						($t \le T_2$) $18\ t^{0,75}\ C_6$ J·m^{-2} / $18\ C_6\ T_2^{-0,25}$ W·m^{-2} ($t > T_2$)		
700 to 1 050	$1,5 \times 10^{-4}\ C_4\ C_6$ J·m^{-2}	$2,7 \times 10^4\ t^{0,75}\ C_4\ C_6$ J·m^{-2}	$5 \times 10^{-3}\ C_4\ C_6$ J·m^{-2}	$18\ t^{0,75}\ C_4\ C_6$ J·m^{-2}		($t \le T_2$) $18\ t^{0,75}\ C_4\ C_6\ C_7$ J·m^{-2} / $18\ C_4\ C_6\ C_7\ T_2^{-0,25}$ W·m^{-2} ($t > T_2$)		
1 050 to 1 400	$1,5 \times 10^{-3}\ C_6\ C_7$ J·m^{-2}	$2,7 \times 10^5\ t^{0,75}\ C_6\ C_7$ J·m^{-2}	$5 \times 10^{-2}\ C_6\ C_7$ J·m^{-2}		$90\ t^{0,75}\ C_6\ C_7$ J·m^{-2}			

[a] The angle γ_{ph} is the limiting measurement angle of acceptance.

[b] In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure must not exceed either limit applicable. Normally, photochemical hazard limits only apply for exposure durations greater than 10 s; however, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of $100\ C_3$ J m^{-2} should be applied for exposures greater than or equal to 1 s.

Table A.3 – Maximum permissible exposure (MPE) of the skin to laser radiation [a, b]

Wave-length λ nm	Exposure time t s					
	$<10^{-9}$	10^{-9} to 10^{-7}	10^{-7} to 10^{-3}	10^{-3} to 10	10 to 10^{3}	10^{3} to 3×10^{4}
180 to 302,5	3×10^{10} W·m^{-2}	30 J·m^{-2}				
302,5 to 315		C_1 J·m^{-2} ($t < T_1$)		C_2 J·m^{-2} ($t > T_1$)	C_2 J·m^{-2}	
315 to 400		C_1 J·m^{-2}			10^{4} J·m^{-2}	10 W·m^{-2}
400 to 700	2×10^{11} W·m^{-2}	200 J·m^{-2}		$1{,}1\times10^{4}\ t^{0{,}25}$ J·m^{-2}	2 000 W·m^{-2}	
700 to 1 400	$2\times10^{11}\ C_4$ W·m^{-2}	200 C_4 J·m^{-2}		$1{,}1\times10^{4}\ C_4\ t^{0{,}25}$ J·m^{-2}	2 000 C_4 W·m^{-2}	
1 400 to 1 500	10^{12} W·m^{-2}	10^{3} J·m^{-2}		5 600 $t^{0{,}25}$ J·m^{-2}	1 000 W·m^{-2} [c]	
1 500 to 1 800	10^{13} W·m^{-2}	10^{4} J·m^{-2}				
1 800 to 2 600	10^{12} W·m^{-2}	10^{3} J·m^{-2}		5 600 $t^{0{,}25}$ J·m^{-2}		
2 600 to 10^{6}	10^{11} W·m^{-2}	100 J·m^{-2}	5 600 $t^{0{,}25}$ J·m^{-2}			

[a] For correction factors and units, see Table 10.

[b] There is only limited evidence about effects for exposures of less than 10^{-9} s. The MPEs for these exposure durations have been derived by maintaining the irradiance applying at 10^{-9} s.

[c] For exposed skin areas greater than 0,1 m^{2}, the MPE is reduced to 100 W·m^{-2}. Between 0,01 m^{2} and 0,1 m^{2}, the MPE varies inversely proportional to the irradiated skin area.

A.2 Limiting apertures

An appropriate aperture should be used for all measurements and calculations of exposure values. This is the limiting aperture and is defined in terms of the diameter of a circular area over which the irradiance or radiant exposure is to be averaged. Values for the limiting apertures are shown in Table A.4.

For repetitively pulsed laser exposures within the spectral range between 1 400 nm and 10^{5} nm, the 1 mm aperture is used for evaluating the hazard from an individual pulse; whereas the 3,5 mm aperture is applied for evaluating the MPE applicable for exposures greater than 10 s.

NOTE The values of ocular exposures in the wavelength range 400 nm to 1 400 nm are measured over a 7 mm diameter aperture (pupil). The MPE must not be adjusted to take into account smaller pupil diameters.

Table A.4 – Aperture diameters for measuring laser irradiance and radiant exposure

Spectral region nm	Aperture diameter for mm	
	Eye	**Skin**
180 to 400	1	3,5
≥ 400 to 1 400	7	3,5
≥ 1 400 to 10^{5}	1 for $t \le 0{,}35$ s $1{,}5\ t^{3/8}$ for $0{,}35\text{ s} < t < 10$ s 3,5 for $t \ge 10$ s	3,5
≥ 10^{5} to 10^{6}	11	11

NOTE For multiple pulse exposures, refer to Clause A.3.

A.3 Repetitively pulsed or modulated lasers

The following methods should be used to determine the MPE to be applied to exposures to repetitively pulsed radiation.

The exposure from any group of pulses (or sub-group of pulses in a train) delivered in any given time should not exceed the MPE for that time.

The MPE for ocular exposure for wavelengths from 400 nm to 10^6 nm is determined by using the most restrictive of requirements a), b) and c). Requirement c) applies only to the retinal thermal limits and not to the retinal photochemical limits.

The MPE for ocular exposure for wavelengths less than 400 nm and the MPE for skin exposure is limited by the most restrictive of requirements a) and b).

a) The exposure from any single pulse within a pulse train does not exceed the MPE for a single pulse.

b) The average exposure for a pulse train of exposure duration T does not exceed the MPE given in Tables A.1, A.2 and A.3 for a single pulse of exposure duration T.

c) 1) For constant pulse energy and pulse duration values

The exposure per pulse does not exceed the MPE for a single pulse multiplied by the correction factor C_5. C_5 is only applicable to individual pulse duration shorter than 0,25 s.

$$\mathrm{MPE}_{\mathrm{s.p.\ train}} = \mathrm{MPE}_{\mathrm{single}} \times C_5$$

NOTE C_5 is only applicable to pulse durations shorter than 0,25 s.

where

$\mathrm{MPE}_{\mathrm{single}}$ is the MPE for a single pulse;

$\mathrm{MPE}_{\mathrm{s.p.\ train}}$ is the MPE for any single pulse in the pulse train;

C_5 $= N^{-1/4}$;

N is the effective number of pulses in the pulse train within the assessed exposure duration (when pulses occur within T_i (see Table 3), N is less than the actual number of pulses, see below). The maximum exposure duration that needs to be considered for the assessment, for wavelengths between 400 nm and 1 400 nm, is T_2 (see Table 10) or the applicable time basis, whichever is shorter. For wavelengths greater than 1 400 nm, the maximum duration to be considered is 10 s.

If multiple pulses appear within the period of T_i (see Table 3) they are counted as a single pulse to determine N, and the radiant exposure of the individual pulses are added to be compared to the MPE of T_i.

2) For varying pulse widths or varying pulse durations

In cases of varying pulse widths or pulse intervals, the total-on-time-pulse (TOTP) method is used. The MPE is determined by the duration of the TOTP, which is the sum of all pulse durations within the exposure duration or T_2, whichever is smaller. Pulses with durations less than T_i are assigned pulse durations of T_i. If two or more pulses occur within a duration of T_i, these pulse groups are assigned pulse durations of T_i. For comparison with the MPE for the corresponding duration, all individual pulse radiant exposures are added.

A.4 Measurement conditions

A.4.1 General

In order to evaluate the actual exposure, the following measurement conditions should be applied.

A.4.2 Limiting aperture

The values of radiant exposure or irradiance to be compared to the respective MPE are averaged over a circular aperture stop according to the limiting apertures of Table A.4. For ocular exposure in the wavelength range from 400 nm to 1 400 nm, a minimum measurement distance of 100 mm is used.

A.4.3 Angle of acceptance

a) Photochemical retinal limits

For measurements of sources to be evaluated against the photochemical limits (400 nm to 600 nm), the limiting angle of acceptance γ_{ph} is

for 10 s < $t \leq$ 100 s: γ_{ph} = 11 mrad

for 100 s < $t \leq 10^4$ s: γ_{ph} = 1,1 $t^{0,5}$ mrad

for 10^4 s < $t \leq 3 \times 10^4$ s: γ_{ph} = 110 mrad

If the angular subtense of the source α is larger than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance should not be larger than the values specified for γ_{ph}. If the angular subtense of the source α is smaller than the specified limiting angle of acceptance γ_{ph}, the angle of acceptance should fully encompass the source under consideration but need not otherwise be well defined (i.e. the angle of acceptance needs not be restricted to γ_{ph}).

NOTE For measurements of single sources where $\alpha < \gamma_{ph}$, it will not be necessary to measure with a specific, well-defined, angle of acceptance. To obtain a well-defined angle of acceptance, the angle of acceptance can be defined by either imaging the source onto a field stop or by masking off the source – see Figures 3 and 4, respectively.

b) All other limits

For measurement of radiation to be compared with limits other than the retinal photochemical hazard limit, the angle of acceptance should fully encompass the source under consideration (i.e. the angle of acceptance should be at least as large as the angular subtense of the source α). However, if $\alpha > \alpha_{max}$, in the wavelength range of 302,5 nm to 4 000 nm, the limiting angle of acceptance should not be larger than α_{max} (0,1 rad) for the thermal hazard limits. Within the wavelength range of 400 nm to 1 400 nm for thermal hazard limits, for the evaluation of an apparent source which consists of multiple points, the angle of acceptance should be in the range of $\alpha_{min} \leq \gamma \leq \alpha_{max}$ (see 8.3 d)).

For the determination of the MPE for sources with non-circular emission patterns, the value of the angular subtense of a rectangular or linear source is determined by the arithmetic mean of the two angular dimensions of the source. Any angular dimension that is greater than α_{max} or less than α_{min} should be limited to α_{max} or α_{min} respectively, prior to calculating the mean. The retinal photochemical hazard limits do not depend on the angular subtense of the source, and the source is measured with the angle of acceptance as specified above.

A.5 Extended source lasers

The following corrections to the small source MPEs are restricted in most instances to viewing diffuse reflections, and, in some cases, these could apply to laser arrays, line lasers, lasers with beam waist diameters above 0,2 mm and divergence angles above 2 mrad or extended source diffused laser products.

For extended source laser radiation (for example, diffuse reflection viewing) at wavelengths from 400 nm to 1 400 nm, the thermal ocular hazard MPEs are increased by the factor C_6 provided that the angular subtense of the source (measured at the viewer's eye) is greater than α_{min}, where α_{min} is equal to 1,5 mrad.

The correction factor C_6 is given by:

$$C_6 = 1 \qquad \text{for } \alpha \le \alpha_{min}$$

$$C_6 = \frac{\alpha}{\alpha_{min}} \qquad \text{for } \alpha_{min} < \alpha \le \alpha_{max}$$

$$C_6 = \frac{\alpha_{max}}{\alpha_{min}} \qquad \text{for } \alpha > \alpha_{max}$$

Annex B
(informative)

Examples of calculations

B.1 Symbols used in the examples of this annex

Symbol	Unit	Definition
a	m	Diameter of the emergent laser beam
AEL	W, J, $W\cdot m^{-2}$ or $J\cdot m^{-2}$	Accessible emission limit
α	rad	The angle subtended by an apparent source (or a diffuse reflection) as viewed at a point in space
α_{min}	rad	Minimum angle subtended by a source for which the extended source criterion applies
$C_1, C_2, ..., C_7$	1	Correction factors (see Table 10)
PRF	Hz	Pulse repetition frequency
H	$J\cdot m^{-2}$	Radiant exposure
E	$W\cdot m^{-2}$	Irradiance at a specified distance, r, from the apparent source
H_o	$J\cdot m^{-2}$	Emergent beam radiant exposure
E_o	$W\cdot m^{-2}$	Irradiance at zero distance from the apparent source
λ	nm	Wavelength of laser radiation
N	1	Number of pulses contained within an exposure duration
P_o	W	Total radiant power (radiant flux) of a CW laser, or average radiant power of a repetitively pulsed laser
P_p	W	Radiant power within a pulse of a pulsed laser
ϕ	rad	Divergence angle of an emergent laser beam
π	1	The numerical constant 3,142
Q	J	Total radiant energy of a pulsed laser
t	s	Time duration of a single laser pulse
T	s	Total exposure duration of a train of pulses
T_1, T_2	s	Time breakpoints (see Table 10)

B.2 Classification of a laser product – Introduction

The examples presented in this annex illustrate the calculation procedures for classifying a laser product from measured parameters obtained by following the measurement conditions specified in this standard. Flowcharts are provided in this Annex to illustrate the basic steps that may be needed to complete a classification calculation for a laser product, but not all possible laser products have been covered by these flowcharts.

As specified in 8.2 and 8.3:

> It is the responsibility of the manufacturer or his agent to provide correct classification of a laser product. The product is classified on the basis of that combination of output power(s) and wavelength(s) of the accessible laser radiation over the full range of capability during operation at any time after manufacture, which results in its allocation to the highest appropriate class. The accessible emission limit (AELs) for Class 1 and 1M, Class 2 and 2M, Class 3R and Class 3B (listed in order of increasing hazard) are given in Tables 4 to 9.
>
> The values of the correction factors used are given in Table 10 as functions of wavelength, emission duration, number of pulses and angular subtense.

If the user modifies the laser product so that the accessible laser radiation is altered, it becomes their responsibility to ensure the product is correctly classified.

The correct classification of a laser product may involve calculating the AEL for more than one of the classes listed in 8.3 to determine the correct classification, as illustrated in Figures B.1 and B.2. Example AELs for Class 1 are presented in Figures B.3 to B.5.

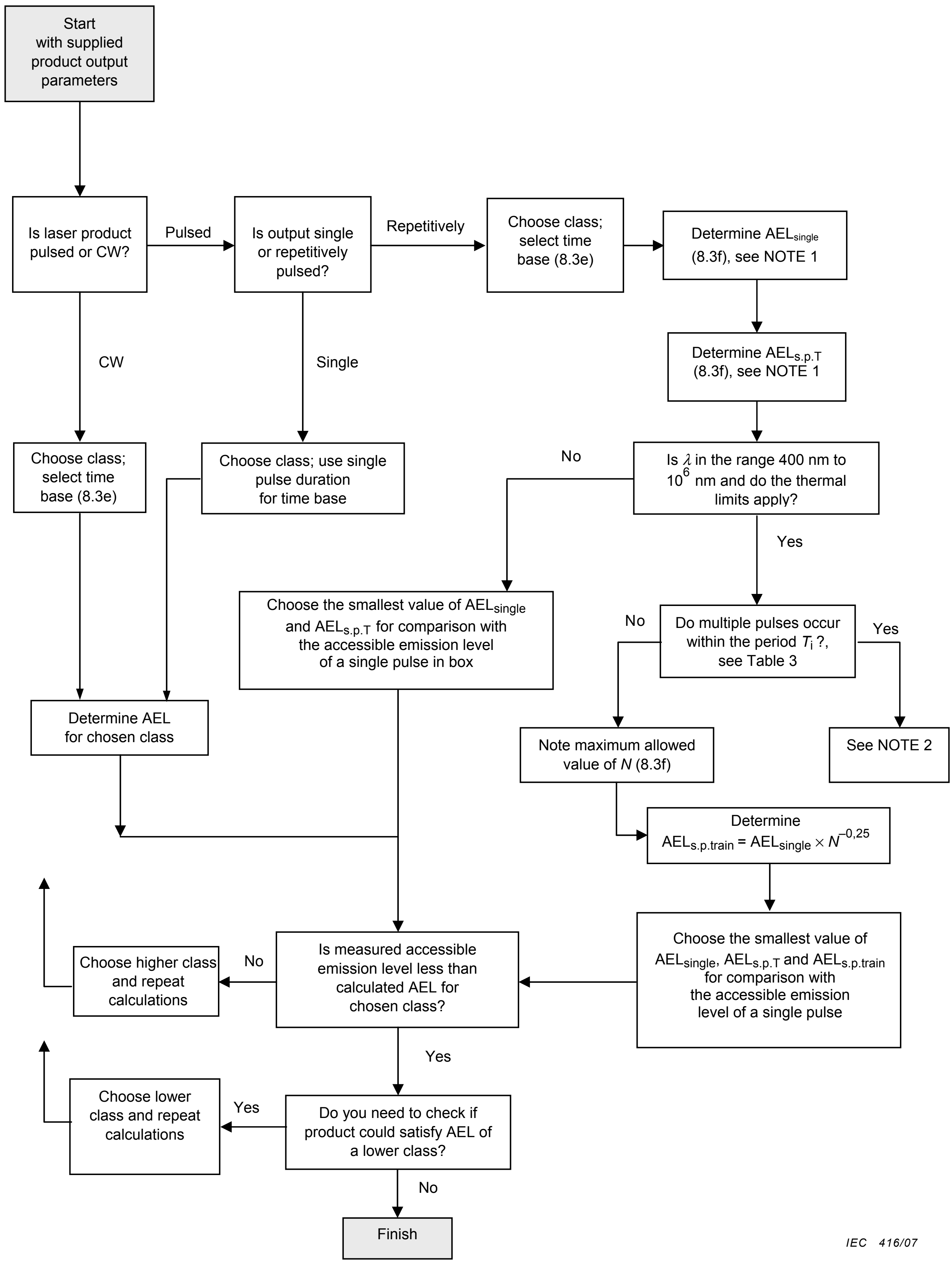


Figure B.1 – Flowchart guide for the classification of laser products from supplied output parameters

NOTE 1
AEL_{single} is determined on the duration of a single pulse.
$AEL_{s.p.T}$ is calculated from AEL_T determined on the chosen time base, where:
If AEL_T is in J or J·m^{-2} then $AEL_{s.p.T} = AEL_T/N_T$ (in units of J or J·m^{-2}).
If AEL_T is in W or W·m^{-2} then $AEL_{s.p.T} = AEL_T$/PRF (in units of J or J·m^{-2}).
T = chosen time base in seconds.
N_T = number of pulses in time T.

NOTE 2
If multiple pulses occur within the period T_i change single pulse duration to T_i and calculate new value of AEL_{single}. Change PRF accordingly to determine maximum allowed value of N (8.3 f). Divide the new value of AEL_{single} by the number of original pulses contained in the period T_i before substituting final value of AEL_{single} in equation for $AEL_{s.p.train}$.

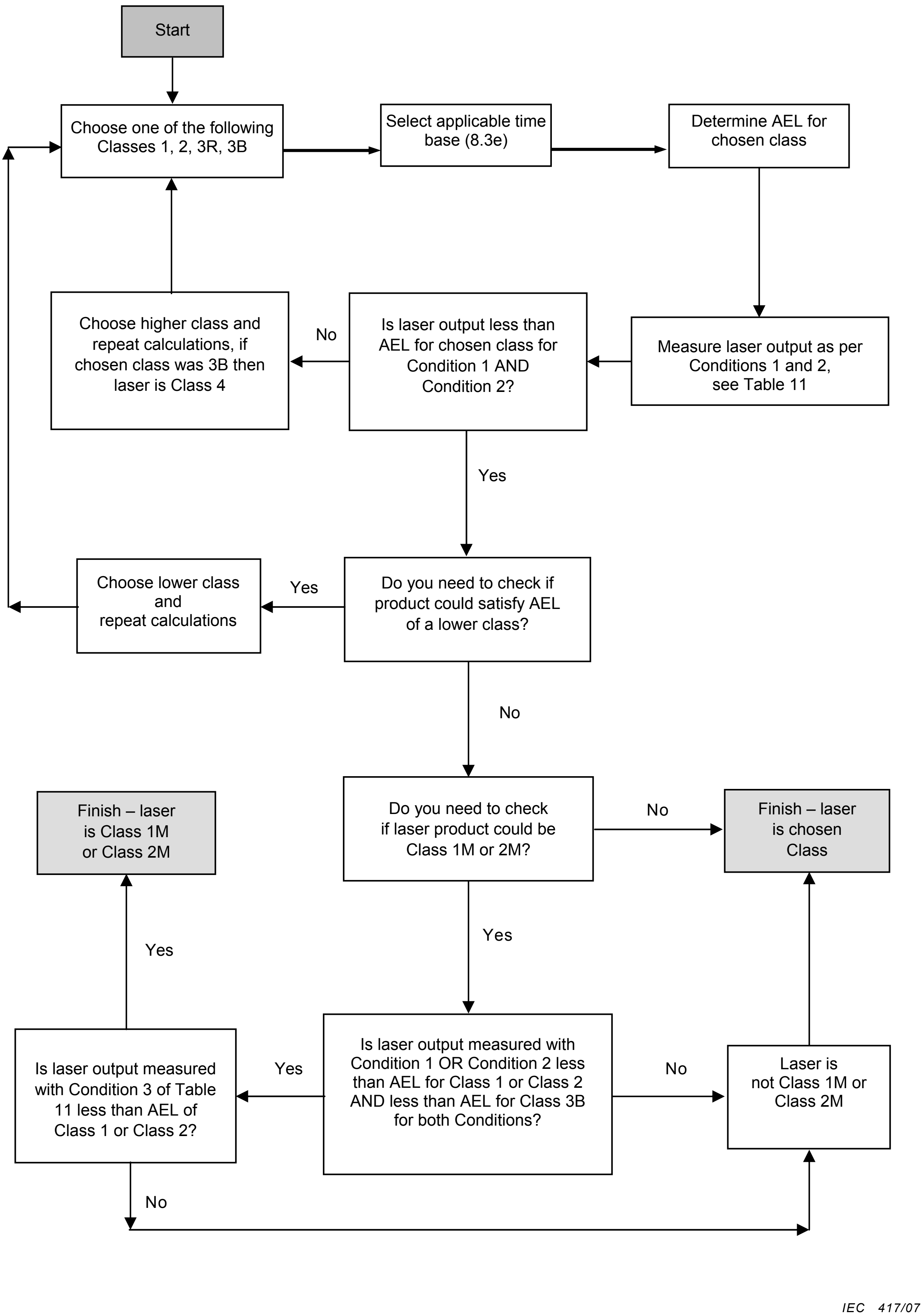


Figure B.2 – Flowchart guide for the classification of Class 1M and Class 2M laser products

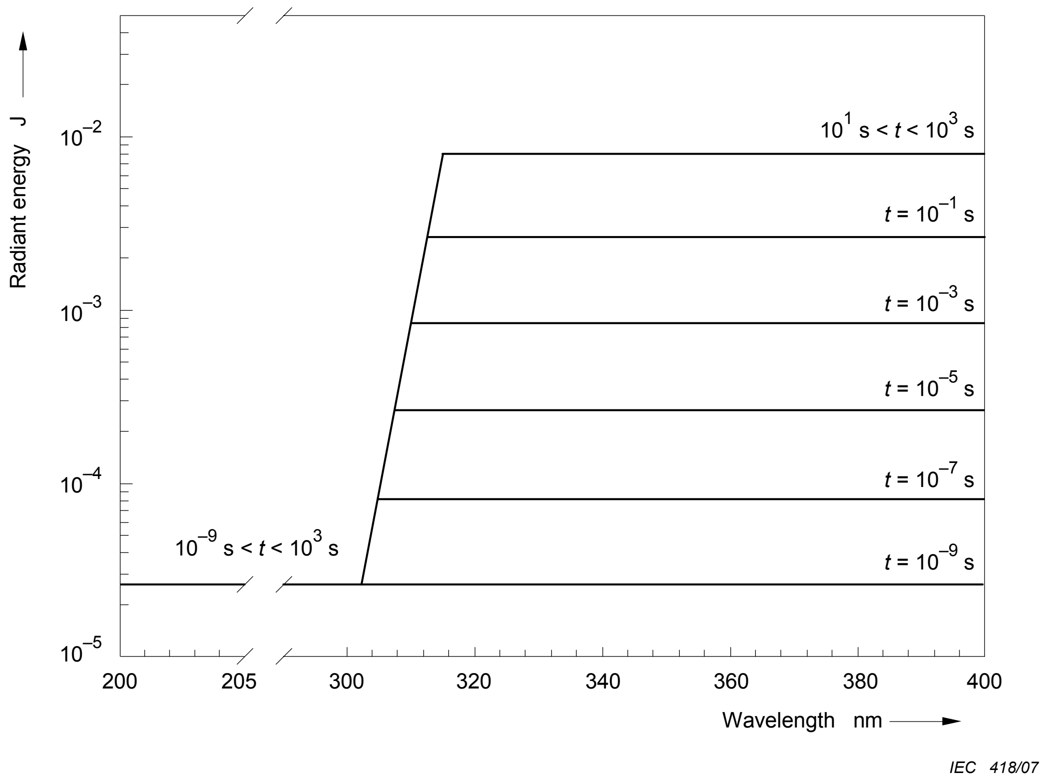


Figure B.3 – AEL for Class 1 ultra-violet laser products for selected emission durations from 10^{-9} s to 10^{3} s

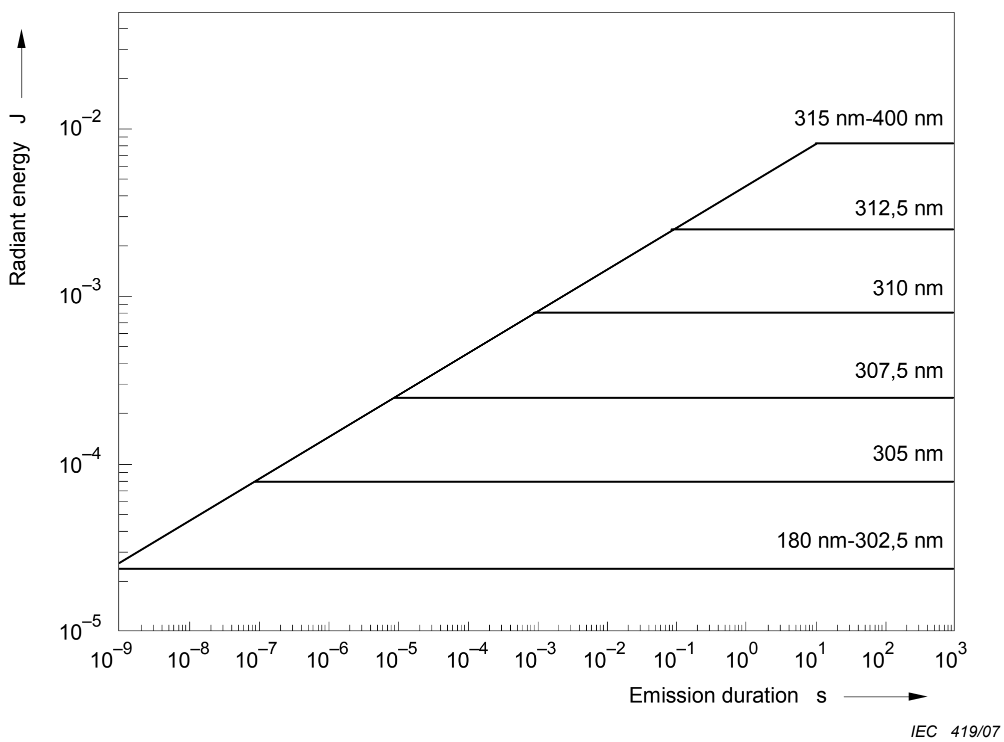


Figure B.4 – AEL for Class 1 ultra-violet laser products for emission durations from 10^{-9} s to 10^{3} s at selected wavelengths

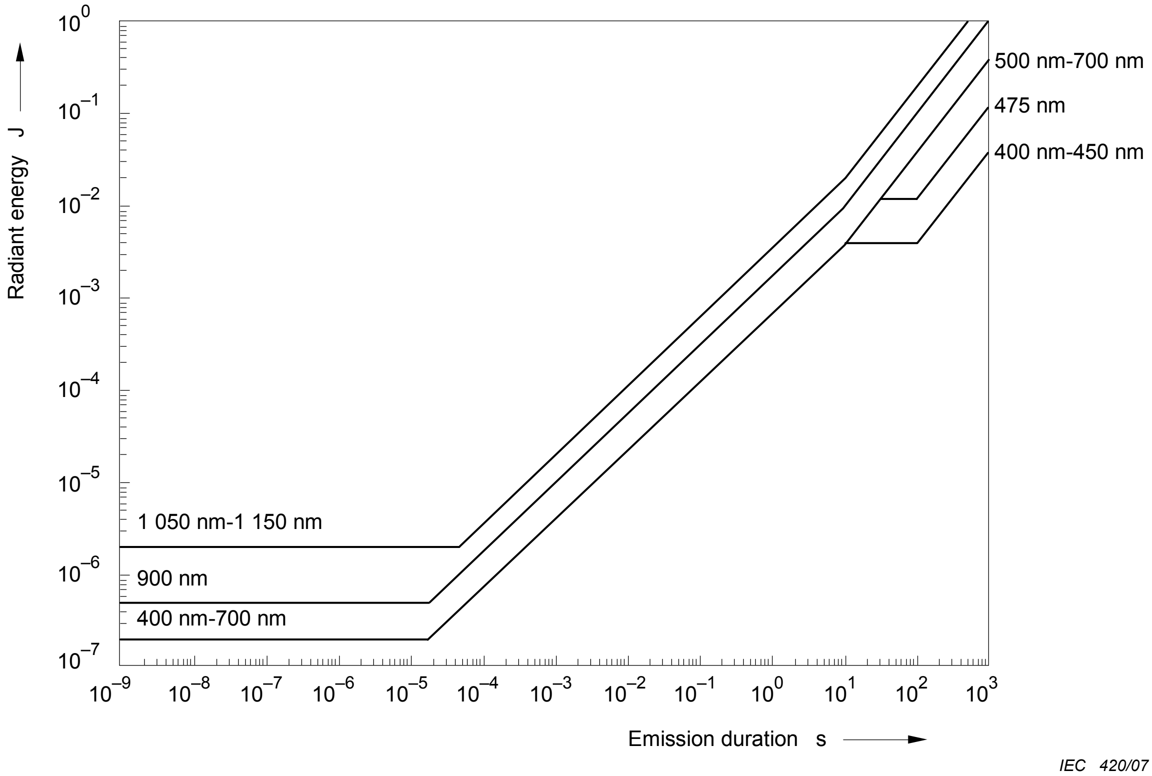


Figure B.5 – AEL for Class 1 visible and selected infra-red laser products (case C_6 = 1)

B.3 Examples

Example B.3.1

Classify a CW HeNe laser (λ = 633 nm), with an output power of 50 mW, beam diameter 3 mm and beam divergence 1 mrad.

Solution:

From the beam characteristics it can be inferred that this is a well-collimated point source where $\alpha \leq \alpha_{min}$ = 1,5 mrad. Because of the small beam diameter and divergence angle, the full beam power will pass through a 7 mm aperture and hence measurement Conditions 1, 2 and 3 will give the same accessible emission level. Choose a classification class and select an appropriate time base (see 8.3e).

Choose Class 3B and a time base of 100 s. Although the laser output is in the visible wavelength range 400 nm to 700 nm, a time base of 0,25 s is not allowed for Class 3B and intentional viewing is unlikely. For Class 3B, Table 8 gives

$$\text{AEL} = 0{,}5 \text{ W}$$

Since the laser is only emitting 50 mW, it does not exceed the AEL for Class 3B and could be classified as Class 3B. However, it may not always be obvious that the product would not satisfy the requirements of a lower classification, hence if in doubt check requirements of a lower class.

For Class 3R a time base of 0,25 s may be used for emission in the wavelength range 400 nm to 700 nm, thus from Table 7,

$$AEL = 5 \times 10^{-3} C_6 \text{ W}$$

From Table 10, $C_6 = 1$ for direct viewing of a well collimated beam, i.e. $\alpha \leq 1{,}5$ mrad, therefore,

$$AEL = 5 \text{ mW}$$

Since laser output power is 50 mW, it exceeds the AEL for Class 3R but is less than the AEL for Class 3B; therefore, the laser would be classified as Class 3B.

Example B.3.2

A 12 mW CW diode laser (λ = 900 nm) without a collimating lens has a beam divergence of 0,5 rad and gave the following parameters for the measurement conditions specified in Table 11. What is its classification? Assume the angular subtense α of the source at a measurement distance of 100 mm is less than α_{min}.

Condition 1: < 20 µW through a 50 mm aperture stop 2 m from the laser diode chip.

Condition 2: 1,4 mW through a 7 mm aperture stop 70 mm from the laser diode chip.

Condition 3: 0,7 mW through a 7 mm aperture stop 100 mm from the laser diode chip.

Solution:

For such a divergent source, it is obvious that condition 2 will be more restrictive than condition 1.

Choose Class 1 and a 100 s time base (see 8.3e); thus, for a laser with $\alpha \leq 1{,}5$ mrad and $t > T_2$ where T_2 = 10 s for $\alpha \leq 1{,}5$ mrad (see Table 10), the AEL is obtained from Table 4 as follows:

$$AEL = 3{,}9 \times 10^{-4} C_4 C_7 \text{ W}$$

Where, from Table 10, $C_4 = 10^{0{,}002(\lambda-700)} = 2{,}51$ and $C_7 = 1$. Therefore,

$$AEL = 0{,}98 \text{ mW}$$

Since this is less than the laser diode is emitting into a 7 mm aperture 70 mm from the laser, it would imply that the product exceeds Class 1 classification for condition 2. However, when we compare the condition 3 data with the AEL for Class 1 laser products the product meets the requirements for Class 1.

Since the product satisfies the requirements for Class 1 classification for Conditions 1 and 3 but fails condition 2 for Class 1, without exceeding the AEL for Class 3B, it is classified Class 1M.

If the user fits a collimating lens to this laser diode, the product may need reclassifying.

Example B.3.3

Classify a single pulsed, frequency doubled, neodymium laser with the following output characteristics, assume both wavelengths are emitted at the same time.

Output pulse energy is 100 mJ at λ = 1 060 nm

Output pulse energy is 25 mJ at λ = 530 nm

Pulse duration = 25 ns

Exit aperture diameter = 5 mm

Beam divergence at each wavelength < 1 mrad

Solution:

Assuming the laser can only emit one pulse in a time base of 100 s, then the duration of the pulse can be used for the exposure duration. Choosing a Class 3B laser product, Table 9 gives the AELs as:

λ = 1 060 nm $\qquad$ AEL_{1060} = 0,15 J = 150 mJ

λ = 530 nm $\qquad$ AEL_{530} = 0,03 J = 30 mJ

The effect of these two wavelengths is additive, see 8.3 b) and Table 2 for classification of laser products with radiation of multiple wavelengths.

Hence need to determine if

$$\frac{Q_{1\,060}}{AEL_{1\,060}} + \frac{Q_{530}}{AEL_{530}} \leq 1$$

Substituting the appropriate values in mJ gives

$$\frac{100}{150} + \frac{25}{30} = 1,5$$

Since this is greater than 1 the laser product must be of higher classification.

Therefore, laser product is Class 4.

Example B.3.4

Classify a carbon dioxide laser (λ = 10,6 μm) used for an open beam security system. Assume an average output power of 0,4 W, a beam diameter of 2 mm and a beam divergence of 1 mrad.

Solution:

Choose Class 3R and a 100 s time base; intentional viewing is not expected.

Table 7 gives the AEL for Class 3R as 5 000 W·m^{-2}. Note, Table 11 gives the limiting aperture for a 100 s exposure as 3,5 mm but the laser beam diameter is only 2 mm. In order to calculate the beam irradiance, ($E_o = P_o$/area), we should use which ever is the greater of the actual beam diameter or the limiting aperture, thus

$$E_0 = \frac{P_0}{\text{area}} = \frac{4 \times 0{,}4}{\pi\left(3{,}5 \times 10^{-3}\right)^2} = 4{,}16 \times 10^4 \text{ W m}^{-2}$$

This exceeds the AEL for Class 3R. Table 9 gives the AEL for Class 3B as 0,5 W; therefore, this laser is classified as Class 3B.

Example B.3.5

Classify a laser emitting 1µs pulses with a pulse repetition frequency of 500 Hz, a peak output power of 10 kW at λ = 694 nm, beam diameter is 5 mm and beam divergence is 0,5 mrad.

Item f) of 8.3 contains details of the requirements for repetitively pulsed lasers, which are summarised below.

The AEL for wavelengths from 400 nm to 10^6 nm is determined by using the most restrictive of requirements a), b) and c) as appropriate. For other wavelengths, the AEL is determined by using the most restrictive of requirements a) and b). Requirement c) applies only to the thermal limits, not to the photochemical limits.

Choose Class 3B and assume a 100 s time base. Check if multiple pulses can occur within the period T_i as given in Table 3. For this laser wavelength $T_i = 18 \times 10^{-6}$ s and the actual time between pulses is 1/PRF = 2×10^{-3} s, hence multiple pulses do not occur in the period T_i. Following the procedure in 8.3 f):

a) Single pulse exposure. Table 9 gives for $t = 10^{-6}$ s,

$$\text{AEL}_{\text{single}} = 0{,}03 \text{ J}$$

b) Table 9 gives the AEL for T = 100 s as follows:

$$\text{AEL}_T = 0{,}5 \text{ W}$$

Dividing by the PRF gives the equivalent AEL energy per pulse; therefore,

$$\text{AEL}_{\text{s.p.T}} = \frac{\text{AEL}_T}{\text{PRF}} = \frac{0{,}5}{500} = 1 \times 10^{-3} \text{ J}$$

c) $\text{AEL}_{\text{s.p.train}} = \text{AEL}_{\text{single}} \times C_5 = \text{AEL}_{\text{single}} \times N^{-0{,}25}$ but N is limited to the number of pulses that occur within the period T_2 = 10 s for $\alpha \le \alpha_{min}$ (see Table 10).

Therefore:

$$\text{AEL}_{\text{s.p.train}} = 0{,}03 \times (10 \times 500)^{-0{,}25} \text{ J}$$

$$\text{AEL}_{\text{s.p.train}} = 3{,}57 \times 10^{-3} \text{ J}$$

The most restrictive of the three values is $\text{AEL}_{\text{s.p.T}} = 1 \times 10^{-3}$ J

The laser energy per pulse, Q, is calculated from the relationship

$$Q = (\text{peak power}) \times (\text{pulse duration})$$

$$Q = 10^4 \times 10^{-6} = 0{,}01 \text{ J}$$

Since the accessible emission energy per pulse exceeds $\text{AEL}_{\text{s.p.T}}$, the laser product exceeds the AEL for Class 3B and, therefore, must be Class 4.

Annex C
(informative)

Description of the classes and potentially associated hazards

C.0 General

This annex contains a description of the classes as well as potentially associated hazards.

The annex is intended as a guide for the manufacturer in their task of describing the hazards associated with the product. This annex also points out limitations of the classification scheme, i.e. situations where the generally associated meaning of the class is not appropriate.

C.1 Introduction

Classification was developed to aid the user in hazard evaluation of the laser and to determine necessary user control measures. Laser classification relates to the potential hazard of the accessible laser radiation in respect to skin or eye damage and does not relate to other potential hazards such as electrical, mechanical or chemical hazards, or hazards from secondary optical radiation. The intent of classification is to recognize the increased risk of injury with increasing powers accessible above the base-line, Class 1 condition and most accurately describes the risk from potential exposures at short distances from the laser. The hazard zone can differ greatly for different lasers within one class. The potential hazard could be greatly reduced by additional user protective measures, including additional engineering controls such as enclosures.

C.2 Description of classes

Class 1

Laser products that are safe during use, including long-term direct intrabeam viewing, even when exposure occurs while using optical viewing instruments (eye loupes or binoculars). Class 1 also includes high power lasers that are fully enclosed so that no potentially hazardous radiation is accessible during use (embedded laser product). Intrabeam viewing of Class 1 laser products which emit visible radiant energy may still produce dazzling visual effects, particularly in low ambient light.

Class 1M

Laser products that are safe, including long-term direct intrabeam viewing for the naked eye (unaided eye). The MPE can be exceeded and eye injury may occur following exposure with one of the two categories of optical viewing instruments (eye loupes or binoculars) under the following conditions:

a) for diverging beams, if the user places optical components within 100 mm from the source to concentrate (collimate) the beam; or
b) for a collimated beam with a diameter larger than the measurement diameter specified for condition 3 (see Table 11).

The wavelength region for Class 1M lasers is restricted to the spectral region where most glass optical materials used in optical instruments can significantly transmit, i.e., between 302,5 nm and 4 000 nm. Intrabeam viewing of Class 1M laser products which emit visible radiant energy may still produce dazzling visual effects, particularly in low ambient light.

Class 2

Laser products that emit visible radiation in the wavelength range from 400 nm to 700 nm that are safe for momentary exposures but can be hazardous for deliberate staring into the beam. The time base of 0,25 s is inherent in the definition of the class and presumption is that there is very low risk of injury for momentary exposures that are somewhat longer.

The following factors contribute to precluding injury under reasonably foreseeable conditions:

- unintentional exposures would rarely reflect worst-case conditions, for example, of beam alignment with the pupil for a stabilised head, worst case accommodation;
- the inherent safety margin in the MPE upon which the AEL is based;
- natural aversion behaviour for exposure to bright light.

For Class 2, in contrast to Class 2M, the use of optical instruments does not increase the risk of ocular injury.

However, dazzle, flash-blindness and afterimages may be caused by a beam from a Class 2 laser product, particularly under low ambient light conditions. This may have indirect general safety implications resulting from temporary disturbance of vision or from startle reactions. Such visual disturbances could be of particular concern connected with performing safety-critical operations such as working with machines or at height, with high voltages or driving.

Users are instructed by labelling not to stare into the beam, i.e. to perform active protective reactions by moving the head or closing the eyes and to avoid continued intentional intrabeam viewing.

Class 2M

Laser products that emit visible laser beams and are safe for short time exposure only for the naked (unaided eye). Eye injury may occur following exposure with one of the two categories of optical viewing instruments (eye loupes or binoculars) under the following conditions:

a) for diverging beams if the user places optical components within 100 mm from the source to concentrate (collimate) the beam; or
b) for a collimated beam with a diameter larger than the measurement diameter specified for condition 3 (see Table 11).

However, dazzle, flash-blindness and afterimages may be caused by a beam from a Class 2M laser product, particularly under low ambient light conditions. This may have indirect general safety implications resulting from temporary disturbance of vision or from startle reactions. Such visual disturbances could be of particular concern if experienced while performing safety-critical operations such as working with machines or at height, with high voltages or driving.

Users are instructed by labelling not to stare into the beam, i.e., to perform active protective reactions by moving the head or closing the eyes, and to avoid continued intentional intrabeam viewing.

Class 3R

Laser products that emit radiation that can exceed the MPE under direct intrabeam viewing, but the risk of injury in most cases is relatively low because the AEL for Class 3R is only 5 times the AEL of Class 2 (visible laser beams) or the AEL of Class 1 (for non-visible laser beams). The risk of injury increases with exposure duration and exposure is hazardous for deliberate ocular exposure. Because of the lower risk, fewer manufacturing requirements and control measures for the user apply than for Class 3B.

The risk is limited because of

- unintentional exposures would rarely reflect worst case conditions of (e.g.) beam alignment with the pupil, worst case accommodation,
- the inherent safety margin in the MPE,
- natural aversion behaviour for exposure to bright light for the case of visible radiation and by the response to heating of the cornea for far infrared radiation.

Dazzle, flash-blindness and afterimages may be caused by a beam from a Class 3R laser product in the visible wavelength range, particularly under low ambient light conditions. This may have indirect general safety implications resulting from temporary disturbance of vision or from startle reactions. Such visual disturbances could be of particular concern if experienced while performing safety-critical operations such as working with machines or at height, with high voltages or driving.

Class 3R lasers should only be used where direct intrabeam viewing is unlikely.

Class 3B

Laser products that are normally hazardous when intrabeam ocular exposure occurs (i.e. within the NOHD) including accidental short time exposure. Viewing diffuse reflections is normally safe. Class 3B lasers which approach the AEL for Class 3B may produce minor skin injuries or even pose a risk of igniting flammable materials. However, this is only likely if the beam has a small diameter or is focussed.

NOTE There exist some theoretical (but rare) viewing conditions where viewing a diffuse reflection could exceed the MPE. For example for Class 3B lasers having powers approaching the AEL, lengthy viewing of greater than 10 s of true diffuse reflections of visible radiation and viewing at distances less than 13 cm between the diffusing surface and the cornea can exceed the MPE.

Class 4

Laser products for which intrabeam viewing and skin exposure is hazardous and for which the viewing of diffuse reflections may be hazardous. These lasers also often represent a fire hazard.

Note on nomenclature

“M” in Class 1M and Class 2M is derived from magnifying optical viewing instruments. “R” in Class 3R is derived from reduced, or relaxed, requirements: reduced requirements both for the manufacturer (e.g. no key switch, beam stop or attenuator and interlock connector required) and the user. The “B” for Class 3B has historical origins, as in the pre-Amendment A2: 2001 version of the standard, a Class 3A existed, which had a similar meaning to what is now Class 1M and Class 2M.

It should be noted that for the above descriptions, whenever “hazardous” is used or there is a reference to a high risk of injury, this hazard and risk only exists within the area around the laser where the corresponding MPE levels are exceeded. For exposure of the naked eye, this area is bounded by the NOHD, or for well collimated Class 1M and 2M viewed with binoculars or telescopes, the extended NOHD (ENOHD). It may well be that a particular (Class 3B or Class 4) laser product has a very short NOHD associated with it, so that for a particular installation or application, for personnel outside the NOHD eye protection is not necessary. Examples of such installations are scanning lasers or line lasers mounted on the ceiling of the manufacturing hall that project a pattern or line onto the workpiece in the work area below. While the power level and scan pattern could be such that the exposure in the work area is below the MPE and therefore safe, maintenance and service routines will need special consideration. For example, exposure at closer distances might be hazardous, for instance, when the user is up on a ladder cleaning an exit window. Another example is that, whilst a scan pattern might be safe, a hazard may arise if the beam reverts to the non-scanning mode. In addition, for Class 4 laser products, there is a NOHD associated with diffuse reflections (although this NOHD is likely to be quite limited in extent). The characterisation of the hazard associated with a particular laser and application is part of a risk assessment.

Classification tests are designed to be rather “worst-case” and restrictive in order to ensure that a “low-class” (e.g. Class 1) product does not present a hazard to the eye or skin even in reasonably foreseeable worst case situations. Consequently, a Class 3B or Class 4 product can still be designed in such a way that it can be considered safe for its intended use and normal operation, since the hazard only becomes accessible in worst case situations. For instance, the product could feature a protective housing (which complies with IEC 60825-4) but fails to be an embedded Class 1 laser product because of the following reasons.

– The housing fails the test according to this Part 1 for an extended period (whereas for machines according to IEC 60825-4 a shorter evaluation time may be used).
– It has no top cover but would be considered safe for an environment where no persons are present above the guard.
– It does not feature an automatic detection of walk-in access. (However, in a controlled environment, this can be replaced by an organisational safety measure of individualised locks that prevent closure of the door when somebody is inside the housing – which does not affect the classification but represents a procedure which achieves the desired level of safety for the user).

In cases where the hazard associated with a Class 3B and Class 4 laser product is limited to within the housing, organisational safety measures may be sufficient. Similarly, for a laser system with no roof, or a situation where burn through of the guard may occur after some longer lasting fault, organisational safety measures may be sufficient.

Other examples exist where the hazards associated with Class 3B and Class 4 lasers arise only in specific situations. For example, consider the situation in which the classification is based on an accessory such as a collimating lens applied to a highly divergent source for low level laser therapy. This product may be classified as Class 3B based on the accessory lens being screwed on, since this lens produces a potentially hazardous collimated beam. However use without the accessory being screwed on, which would result in a divergent beam, could be safe (i.e. any exposure to the eye would be below the MPE). Thus a hazard area would only exist around the laser once the accessory has been screwed on.

C.3 Limitations of the classification scheme

Although the classification tests are in many ways rather restrictive and worst case, there are still limitations which, in rare cases, may lead to hazards beyond the hazards that are associated with the respective classes. Classification is based on three "components":

a) the AEL of the different classes;

b) the measurement requirements in terms of measurement distance, aperture diameter and angle of acceptance to reflect potential exposure conditions. These measurement requirements, for a given laser product, determine the accessible emission that is compared to the AEL to determine the class;

c) the test conditions under which the AEL and the accessible emission is determined. This would include taking account of reasonably foreseeable single fault conditions. Also operational, maintenance and service need to be distinguished. The use of accessories and different configurations of the product that can be achieved without using tools needs to be considered.

Each of these three components has some implicit assumptions, so that in rare cases, where these assumptions are not met, hazards beyond the usual understanding of the class can arise. For instance, the AEL for Class 1 and 1M for long term exposure is based on the assumption of eye movements of a non-anaesthetised eye. However, if prolonged ocular exposure occurs during medical procedures for an anaesthetised eye, then Class 1 laser emission may lead to potentially hazardous exposures. Also, the measurement requirements are based on assumptions and evaluations of the likelihood of exposure with certain types of optical instruments. For example, a large diameter collimated beam intercepted by a large telescope might be hazardous even for a Class 1 laser product. However, the probability of such an accidental ocular exposure is usually very small due to the small field of view of the telescope. Another situation that might need to be considered is where a product is placed into a condition which is not required to be considered for classification but from which hazardous radiation might, nevertheless, become accessible. For instance, even though it is not provided by the manufacturer of the product as an accessory, a divergent beam from a Class 1M or Class 2M product could be transformed into a collimated beam with a potentially large hazard distance by attaching a collimating lens to the product. However, this would be considered as changing the product, and the person carrying out that change should re-classify the product.

Nevertheless, the manufacturer should be aware of the limitations so that it is possible to include warnings in the user manual for products. Specific examples of such potential limitations are given below (note that these limitations are only potential because it depends on the type of product if the limitations apply or not).

– Large diameter collimated beam Class 1, Class 2 or Class 3R laser products that are viewed with large telescopes.
– Highly divergent beam Class 1, Class 2 or Class 3R laser products that are viewed with magnifiers with large magnification.
– Binoculars or telescopes with magnification of less than ×7. In this case, for condition 1, the magnification of the angular source α that may be applied (see 8.3 c)), or, alternatively, the reduction of the angle of acceptance (see 9.3.2 b)), should be equal to the real magnification factor, i.e. less than ×7.
– Scanning beams when viewed with telescopes.
– Double fault conditions that might be likely. That is, faults where each fault on its own would not result in accessible emission above the AEL, but both faults occurring at the same time could. When these faults are expected to occur with a relatively high probability, then the probability for a double fault might be sufficiently high so that it should be considered during product design.

Annex D
(informative)

Biophysical considerations

D.1 Anatomy of the eye

Figure D.1 provides anatomical details of the human eye.

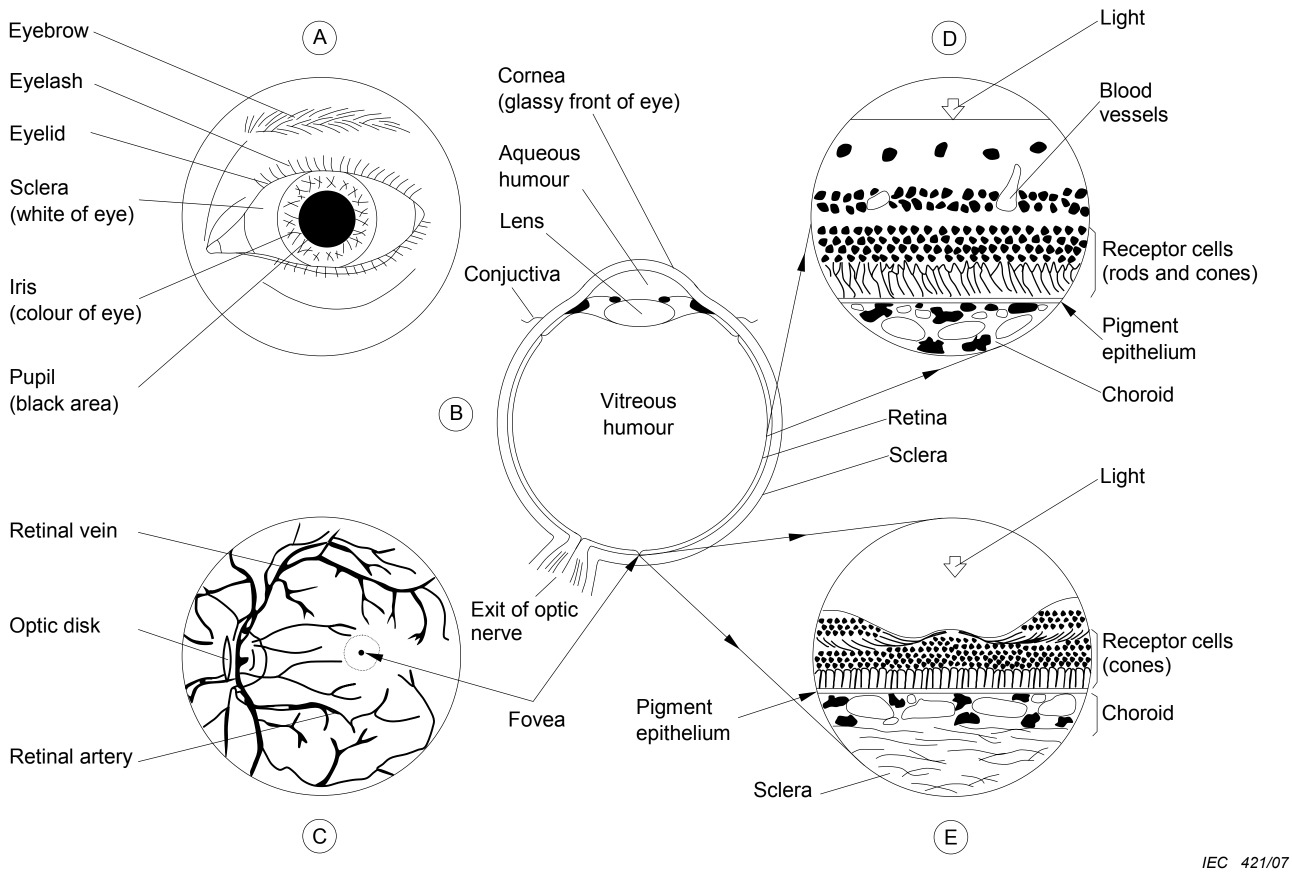


Figure D.1 – Anatomy of the eye

In Figure D.1, section (A) is a diagram of the external features of a left eye. The gap between the overlying lids limits the field-of-view (FOV) of the eye to an almond shape. The main features of the front of the eye are labelled.

Section (B) is a diagrammatic horizontal cross-section of a left eye. The eye is divided into two parts, the front or anterior chamber which is bounded by the cornea, the iris and the lens, and the back or posterior eye cup which is bounded by the retina and contains the gel-like vitreous humour.

Section (C) is the inside of an intact eye seen through an ophthalmoscope. This instrument directs a beam of light through the pupil and illuminates the inside of the eye and so allows it to be seen. The picture so viewed is referred to as the fundus. It looks reddish, but the major retinal vessels can be clearly seen. Other prominent features are the whitish optic disc, and the fovea. The fovea is a small depression in the retinal surface which may be more pigmented than the surrounding retina and is the area of most acute vision. The fovea is the centre of the macula; the macula is responsible for detailed vision.

Section (D) is the structure of the retina as seen in the cut surface of Figure D.1(B) but magnified several hundreds times larger than life. The retina consists of a series of layers of nerve cells which overlie the photosensitive rod and cone cells; i.e. light falling on the retinal surface has to pass through the layers of nerve cells before it reaches the photosensitive cells. Underneath the layer of rods and cones is a layer of the pigment epithelium that contains a brownish black pigment melanin; and beneath this is a layer of fine blood vessels, the choriocapillaris. The final absorbing layer is the choroid, which contains both pigmented cells and blood vessels.

Section (E) is the structure of the foveal region magnified several hundreds times. Here only cones are present. The nerve cells are displaced radially away from this area of most acute vision. The macular pigment, which absorbs strongly from 400 nm to 500 nm, is located in the fibre layer of Henle.

D.2 The effects of laser radiation on biological tissue

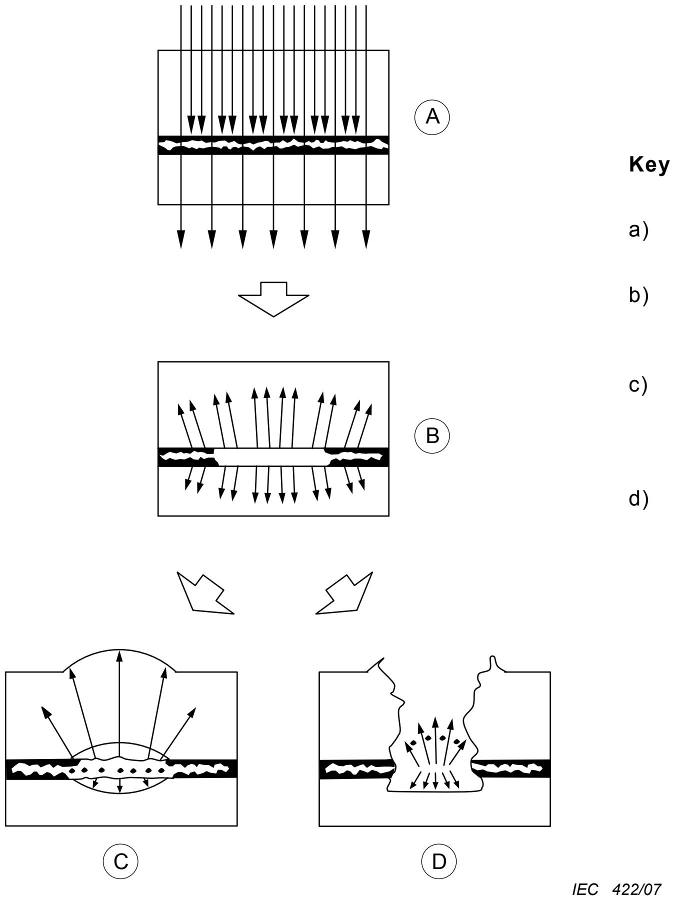
D.2.1 General

The mechanism by which laser radiation induces damage is similar for all biological systems and may involve interactions of heat, thermoacoustic transients, photochemical processes and non-linear effects. The degree to which any of these mechanisms is responsible for damage may be related to certain physical parameters of the irradiating source, the most important of which are wavelength, pulse duration, image size, irradiance and radiant exposure.

In general terms, in supra-threshold exposures, the predominating mechanism is broadly related to the pulse duration of the exposure. Thus, in order of increasing pulse duration, the predominant effects in the following time domains are:

– in nanosecond and sub-nanosecond exposures, acoustic transients and non-linear effects,
– from 1 ms to several seconds, thermal effects, and,
– in excess of 10 s, photochemical effects.

Laser radiation is distinguished from most other known types of radiation by its beam collimation. This, together with an initial high energy content, results in excessive amounts of energy being transmitted to biological tissues. The primary event in any type of laser radiation damage to a biological system is the absorption of optical radiation by that system. Absorption occurs at an atomic or molecular level and is a wavelength specific process. Thus, it is the wavelength that determines which tissue a particular laser beam is liable to damage.



Key

a) Laser energy is absorbed by the system.

b) The absorbed energy produces heat which is conducted to surrounding tissues.

c) In long-pulse or CW lasers, the persistence of the thermal front gives rise to a progressively enlarging lesion.

d) In short-pulse lasers, the high power density gives rise to explosive rupture of cells and damage by physical displacement.

Figure D.2 – Diagram of laser-induced damage in biological systems

Thermal effects. When sufficient radiant energy has been absorbed by a system, its component molecules experience an increased vibration, and this is an increase in heat content. Most laser damage is due to the heating of the absorbing tissue or tissues. This thermal damage is usually confined to a limited area extending to either side of the laser energy absorbing site, and centred on the irradiating beam. Cells within this area show burn characteristics, and tissue damage primarily results from denaturation of protein. As indicated above, the occurrence of secondary damage mechanisms in laser impacts can be related to the time course of the tissue heating reaction which is directly related to the pulse duration (see Figure D.2) and the period of cooling. Thermochemical reactions occur during both the heating and cooling period, giving rise to a spot-size dependence of thermal injury. If a CW or long-pulse laser impulse is directed onto a tissue, then because of conduction, the area of the biological tissue experiencing a raised temperature is progressively increased. This spreading thermal front results in an increasing damage zone as more and more cells are raised above their thermal tolerance. The beam image size is also of great importance, as the degree of

peripheral spread due to conduction is a function of the size as well as the temperature of the initial area of tissue heating. This type of thermal lesion is commonly seen on exposure to CW or long pulsed lasers, but also occurs with short pulses. For irradiated spot sizes of the order of 1 mm to 2 mm or less, the radial heat flow leads to a spot-size dependence of injury.

Photochemical effects. On the other hand, damaging effects can be the direct result of a photochemical process. This process is created by absorption of given light energy. Rather than releasing the energy, the species undergo a chemical reaction unique to their excited state. This photochemical reaction is believed to be responsible for damage at low levels of exposure. By this mechanism, some biological tissues such as the skin, the lens of the eye, and in particular the retina may show irreversible changes induced by prolonged exposure to moderate levels of UV radiation and short-wavelength light. Such photochemically induced changes may result in damage to a system if the duration of irradiation is excessive, or if shorter exposures are repeated over prolonged periods. Some of the photochemical reactions initiated by laser exposure may be abnormal, or exaggerations of normal processes. Photochemical reactions generally follow the Law of Bunsen and Roscoe, for duration of the order of 1 h to 3 h or less (where repair mechanisms cannot cope with the rate of damage); the threshold expressed as a radiant exposure is constant over a wide range of exposure duration. The spot-size dependence, as occurs with thermal effects due to heat diffusion, does not exist.

Non-linear effects. Short-pulsed high peak-power (i.e., Q-switched or mode-locked) lasers may give rise to tissue damage with a different combination of induction mechanisms. Energy is delivered to the biological target in a very short time and hence a high irradiance is produced. The target tissues experience such a rapid rise in temperature that the liquid components of their cells are converted to gas. In most cases, these phase changes are so rapid that they are explosive and the cells rupture. The pressure transients may result from thermal expansion and both may also result in shearing damage to tissues remote from the absorbing layers by bulk physical displacement. At sub-nanosecond exposures, self-focusing of the ocular media further concentrates laser energy from a collimated beam and further lowers the threshold between approximately 10 ps and 1 ns. Furthermore, other non-linear optical mechanisms appear to play a role in retinal injury in the sub-nanosecond region.

All of the above-described damage mechanisms have been shown to operate in the retina, and are reflected in the breakpoints or changes of slope in the safe exposure levels described in this standard.

D.2.2 Hazards to the eye

A brief description of the anatomy of the eye is given in Clause D.1. The eye is specially adapted to receive and transduce optical radiation. The pathologies caused by excessive exposures are summarized in Table D.1. Thermal interaction mechanisms are shown in Figure D.2. Lasers emitting ultra-violet and far infra-red radiation represent a corneal hazard while systems emitting visible and near infra-red wavelengths will be transmitted to the retina.

Visible and near infra-red laser beams are a special hazard to the eye because the very properties necessary for the eye to be an effective transducer of light result in high radiant exposure being presented to highly pigmented tissues. The increase in irradiance from the cornea to the retina is approximately the ratio of the pupil area to that of the retinal image. This increase arises because the light which has entered the pupil is focused to a "point" on the retina. The pupil is a variable aperture but the diameter may be as large as 7 mm when maximally dilated in the young eye. The retinal image corresponding to such a pupil may be between 10 μm and 20 μm in diameter. With intra-ocular scattering and corneal aberrations considered, the increase in irradiance between the cornea and the retina is of the order of 2×10^5.

Table D.1 – Summary of pathological effects associated with excessive exposure to light

CIE spectral region [a]	Eye	Skin
Ultra-violet C (180 nm to 280 nm)	Photokeratitis	Erythema (sunburn) Accelerated skin ageing process Increased pigmentation
Ultra-violet B (280 nm to 315 nm)		
Ultra-violet A (315 nm to 400 nm)	Photochemical cataract	Pigment darkening Photosensitive reactions Skin burn
Visible (400 nm to 780 nm)	Photochemical and thermal retinal injury	
Infra-red A (780 nm to 1 400 nm)	Cataract, retinal burn	Skin burn
Infra-red B (1,4 μm to 3,0 μm)	Aqueous flare, cataract, corneal burn	
Infra-red C (3,0 μm to 1 mm)	Corneal burn only	

[a] The spectral regions defined by the CIE are short-hand notations useful in describing biological effects and may not agree perfectly with spectral breakpoints in the MPE Tables A.1 to A.3.

If an increase of 2×10^5 is assumed, a 50 $W \cdot m^{-2}$ beam on the cornea becomes 1×10^7 $W \cdot m^{-2}$ on the retina. In this standard, a 7 mm pupil is considered as a limiting aperture as this is a worst-case condition and is derived from figures obtained from the young eye where pupillary diameters of this order have been measured. An exception to the assumption of a 7 mm pupil was applied in the derivation of exposure limits to protect against photoretinitis whilst viewing bright visible (400 nm to 700 nm) laser sources for periods in excess of 10 s. In this latter situation, a 3 mm pupil was assumed as a worst-case condition; however, a 7 mm irradiance averaging aperture for measurement was still considered appropriate due to physiological movements of the pupil in space. Hence, AELs for durations greater than 10 s are still derived for a 7 mm aperture.

If an intense beam of laser light is brought to a focus on the retina, only a small fraction of the light (up to 5 %) will be absorbed by the visual pigments in the rods and cones. Most of the light will be absorbed by the pigment called melanin contained in the pigment epithelium. (In the macular region, some energy in the 400 nm to 500 nm range will be absorbed by the yellow macular pigment.) The absorbed energy will cause local heating and will burn both the pigment epithelium and the adjacent light sensitive rods and cones. This burn or lesion may result in a loss of vision. Photochemical injuries, although non-thermal, are also localized in the pigment epithelium.

Depending on the magnitude of the exposure, such a loss of vision may or may not be permanent. A visual decrement will usually be noted subjectively by an exposed individual only when the central or foveal region of the macula is involved. The fovea, the pit in the centre of the macula, is the most important part of the retina as it is responsible for sharpest vision. It is the portion of the retina that is used "to look right at something". This visual angle subtended by the fovea is approximately equal to that subtended by the moon. If this region is damaged, the decrement may appear initially as a blurred white spot obscuring the central area of vision; however, within two or more weeks, it may change to a black spot. Ultimately, the victim may cease to be aware of this blind spot (scotoma) during normal vision. However, it can be revealed immediately on looking at an empty visual scene such as a blank sheet of white paper. Peripheral lesions will only be registered subjectively when gross retinal damage has occurred. Small peripheral lesions will pass unnoticed and may not even be detected during a systematic eye examination.

In the wavelength range from 400 nm to 1 400 nm, the greatest hazard is retinal damage. The cornea, aqueous humour, lens and vitreous humor are transparent for radiation of these wavelengths. In the case of a well-collimated beam, the hazard is virtually independent of the distance between the source of radiation and the eye, because the retinal image is assumed to be a diffraction-limited spot of around 10 μm to 20 μm diameter. In this case, assuming thermal equilibrium, the retinal zone of hazard is determined by the limiting angular subtense α_{min}, which generally corresponds to retinal spot of approximately 25 μm in diameter.

In the case of an extended source, the hazard varies with the viewing distance between the source and the eye, because whilst the instantaneous retinal irradiance only depends on the source's radiance and on the lens characteristics of the eye, thermal diffusion of energy from larger retinal images is less efficient, leading to a retinal spot-size dependence for thermal injury which does not exist for photochemical injury (dominating only in the 400 nm to 600 nm spectral region). In addition, eye movements further spread the absorbed energy for CW laser exposures, leading to different dependencies of risk for differing retinal image sizes.

In the derivation of limits for ocular exposure in the retinal hazard region, correction factors for eye movements were only applied for viewing durations exceeding 10 s. Although physiological eye movements known as saccades do spread the absorbed energy in minimal retinal images (of the order of 25 μm or less) within the 0,1 s to 10 s time regime, the limits provide a desired added safety factor for this viewing condition. At 0,25 s, the mean retinal spot illuminated is approximately 50 μm. By 10 s, the illuminated retinal zone becomes approximately 75 μm and the added safety factor for the minimal image condition becomes 1,7 over a stabilized eye, with the spot-size dependence taken into account. By 100 s, it is rare to achieve an illuminated zone (measured at 50 % points) as small as 135 μm leading to an additional safety factor of 2,3 or more for the minimal image condition.

The data from eye-movement studies and retinal thermal injury studies were combined to derive a break-point in viewing time T_2 at which eye movements compensated for the increased theoretical risk of thermal injury for increased retinal exposure durations if the eye were immobilized. Because the thermal injury threshold expressed as radiant power entering the eye decreases as the exposure duration t raised to the –0,25 power (i.e. a reduction of only 44 % per tenfold increase in duration), only moderate increases in the exposed retinal area will compensate for the increased risk for longer viewing times. The increasing retinal area of irradiation resulting from greater eye movements with increased viewing time takes longer to compensate for the reduced impact of thermal diffusion in larger extended sources. Thus, for increasing angular subtense α, the break-point T_2 increases from 10 s for small sources to 100 s for larger sources. Beyond 100 s, there is no further increase in risk of thermal injury for small and intermediate size images. The specification of limits and measuring conditions attempt to follow these variables with some simplification leading to a conservative determination of risk. It is conservatively assumed that retinal thermal injury thresholds vary inversely with retinal image size (stabilized) between approximately 25 μm to 1 mm (corresponding to angular sizes of 1,5 mrad to 59 mrad), whilst beyond 1,7 mm (corresponding to angular sizes greater than 100 mrad), there is no spot-size dependence.

For photochemically induced retinal injury, there is no spot size dependence for a stabilized image. Unlike thermal injury mechanism, the thresholds for photochemical injury are highly wavelength dependent and are exposure dose dependent, i.e. the thresholds decrease inversely with the lengthening of exposure duration. Studies of photochemical retinal injury from welding arcs subtending angles of the order of 1 mrad to 1,5 mrad showed typical lesion sizes of the order of 185 μm to 200 μm (corresponding to visual angles of 11 mrad to 12 mrad), clearly showing the influence of eye movements during fixation; these and other studies of eye movements during fixation led to the derivation of MPEs to protect against photochemical retinal injury. These studies also led to MPE irradiance to be specified as being averaged over 11 mrad for exposure durations between 10 s and 100 s. Hence, sources with an angular subtense α less than 11 mrad were treated equally with "point-type" sources, and the concept of α_{min} was extended to CW laser viewing. This approach was not strictly correct, as an irradiance measurement of an 11 mrad source is not equivalent to irradiance averaging over a field of view (γ) of 11 mrad unless the source had a rectangular ("top-hat") radiance distribution. Hence, in this edition of the standard, distinction is made between angular subtense of a source and irradiance averaging for photochemical MPE values. For viewing times in excess of approximately 30 s to 60 s, the saccadic eye motion during fixation is generally overtaken by behavioural movements determined by visual task, and it is quite unreasonable to assume that a light source would be imaged solely in the fovea for durations longer than 100 s. For this reason, the angle of acceptance γ_{ph} is increased linearly with the square-root of t. The minimal angular subtense α_{min} correctly remains at the reference angle of 1,5 mrad for all exposure durations used in thermal retinal hazard evaluation. However, for photochemical retinal hazard assessment, the concept is actually different, as the angle γ_{ph} is a linear angle of acceptance for the measurement of irradiance, and this is important to apply only for extended sources greater than approximately 11 mrad.

Viewing distance. In the case of a "point-type", diverging-beam source, the hazard increases with decreasing distance between the beam waist and the eye. The reason is that, with decreasing distance, the collected power increases, while the size of the retinal image can be assumed to remain nearly diffraction-limited for true laser sources down to a distance as close as 100 mm (due to the accommodation capabilities of the eye). The greatest hazard occurs at the shortest accommodation distance. With further reduced distance, the hazard to the unaided eye is also reduced, as there is a rapid growth of the retinal image and a corresponding reduction of the irradiance, even though more power may be collected. To simulate the risk of optically aided viewing of a collimated beam with binoculars or a telescope, the closest distance of approach of 2 m with a 50-mm aperture was assumed based upon the closest distance for clear viewing.

For the purpose of this standard, the shortest accommodation distance of the human eye is set to 100 mm at all wavelengths from 400 nm to 1 400 nm. This was chosen as a compromise, because all but a few young people and very few myopics cannot accommodate their eyes to distances of less than 100 mm. This distance may be used for the measurement of irradiance in the case of intrabeam viewing (see Table 11).

For wavelengths of less than 400 nm or more than 1 400 nm, the greatest hazard is damage to the lens or the cornea. Depending on the wavelength, optical radiation is absorbed preferentially or exclusively by the cornea or the lens (see Table D.1). For diverging-beam sources (extended or point-type) of these wavelengths, short distances between the source and the eye should be avoided.

In the wavelength range from 1 500 nm to 2 600 nm, radiation penetrates into the aqueous humour. The heating effect is therefore dissipated over a greater volume of the eye, and the MPEs are increased for exposures less than 10 s. The greatest increase in the MPEs occurs for very short pulse durations and within the wavelength range of 1 500 nm to 1 800 nm where the absorbing volume is greatest. At times greater than 10 s, heat conduction redistributes the thermal energy so that the impact of the penetration depth is no longer significant.

D.2.3 Skin hazards

In general terms, the skin can tolerate a great deal more exposure to laser beam energy than can the eye. The biological effect of irradiation of skin by lasers operating in the visible (400 nm to 700 nm) and infra-red (greater than 700 nm) spectral regions may vary from a mild erythema to severe blisters. An ashen charring is prevalent in tissues of high surface absorption following exposure to very short-pulsed, high-peak power lasers. This may not be followed by erythema.

The pigmentation, ulceration, and scarring of the skin and damage of underlying organs may occur from extremely high irradiance. Latent or cumulative effects of laser radiation have not been found prevalent. However, some limited research has suggested that under special conditions, small regions of human tissue may be sensitized by repeating local exposures with the result that the exposure level for minimal reaction is changed and the reactions in the tissues are more severe for such low-level exposure.

In the wavelength range 1 500 nm to 2 600 nm, biological threshold studies indicate that the risk of skin injury follows a similar pattern to that of the eye. For exposures up to 10 s, the MPE is increased within this spectral range.

D.3 MPEs and irradiance averaging

In this standard, the maximum permissible exposure (MPE) values recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) have been adopted. The irradiance-averaging apertures (measurement apertures) recommended by the ICNIRP were adopted, or an additional safety factor applied by IEC TC76. The determination and derivation of the AELs, although generally based upon the MPEs, necessitated a risk analysis and determination of reasonably foreseeable exposure conditions. The choice of measurement aperture played a role in the derivation of AELs and reflects both biophysical and physiological factors. In some cases, considerations of risk assessment and simplification of expression played a role. Table D.2 provides a summary of the factors assumed in the choice of measurement apertures. In general, the recommendations of ICNIRP were followed, or added safety factors applied.

Table D.2 – Explanation of measurement apertures applied to the MPEs

Spectral band λ nm	**Exposure duration** t	**Aperture diameter** mm	**Comments and rationale for aperture diameter**
180 to 400	$t < 3 \times 10^4$ s	1 mm	Scatter in corneal epithelium and in stratum corneum leads to 1 mm; assumption of no movement of exposed tissue for continuous exposure conditions is applied by IEC. However, ICNIRP recommends 3,5 mm for lengthy exposures due to eye movements
400 to 600 photochemical	$t > 10$ s	3 mm in derivation of MPE, but 7 mm used for measurements	Lateral motion of 3-mm diameter pupil in space to produce 7-mm aperture averaging for CW exposures applicable for photochemical injury mechanism
400 to 1 400 thermal	All t	7 mm	Diameter of dilated pupil and lateral motion in CW exposures
$\lambda > 1\,400$	$t < 0,35$ s	1 mm	Thermal diffusion in stratum corneum and epithelial tissues
$\lambda > 1\,400$	$0,35 \text{ s} < t < 10$ s $t > 10$ s	$1,5 \times t^{3/8}$ mm 3,5 mm	Greater thermal diffusion and movement of target tissue relative to beam after 0,35 s
$10^5 \leq \lambda \leq 10^6$	All t	11 mm	Aperture to be greater than diffraction limit (i.e., approximately 10×) for accurate measurements

D.4 Reference documents

1 HENDERSON, R. and SCHULMEISTER, K.: *Laser Safety*, Institute of Physics Publishing, Bristol, 2003

2 International Commission on Non-Ionizing Radiation Protection (ICNIRP): *Guidelines on limits of exposure to laser radiation of wavelengths between 180 nm and 1,000 µm*. Health Phys. 71(5): 804-819, 1996.

3 International Commission on Non-Ionizing Radiation Protection (ICNIRP): *Revision of guidelines on limits of exposure to laser radiation of wavelengths between 400 nm and 1,4 µm.* Health Phys. 79(4):431-440, 2000.

4 NESS, J., ZWICK, H.A., STUCK, B.A., LUND, D.J., MOLCHANY, J.A. and SLINEY, D.H.: *Retinal image motion during deliberate fixation: implications to laser safety for long duration viewing*. Health Phys. 78(2):131-142.

5 ROACH, W.P., JOHNSON, P.E. and ROCKWELL, B.A.*: Proposed maximum permissible exposure limits for ultrashort laser pulses*, Health Phys. 76(4):349-354.

6 SLINEY, D.H. and WOLBARSHT, M.L.: *Safety with Lasers and Other Optical Sources,* New York, Plenum Publishing Corp., 1980.

7 SLINEY, D., ARON-ROSA, D., DELORI, F., et al: *Adjustment of guidance for exposure of the eye to optical radiation from ocular instruments: statement of a task group of the International Commission on Non-Ionizing Radiation Protection*, Applied Optics, 44(11), 2162-2176, 2005

8 United Nations Environment Programme (UNEP); World Health Organization (WHO); International Radiation Protection Association (IRPA): *Environmental Health Criteria No. 23: Lasers and Optical Radiation*, Geneva, WHO, 1982.

Annex E
(informative)

MPEs and AELs expressed as radiance

E.1 Background

For large extended sources, it may be easier to analyze potential retinal hazards by using the radiance of the source. This annex is to provide users with a single table and graphs of maximum permitted radiances based on the AELs for Class 1 and Class 1M and corresponding MPE values in the retinal hazard wavelength region of 400 nm to 1 400 nm for viewing conditions where the angular subtense of the apparent source is assumed to be larger than α_{max}. By the law of conservation of radiance, all extended sources that are diffused and emitting below the radiance level specified in the Table E.1 or on the Figure E.1 cannot exceed Class 1 accessible emission limits (AELs) regardless of the optics placed in front of a diffused source.

E.2 Radiance values

The radiance values in Table E.1 are based upon the IEC/ICNIRP MPE levels. As MPEs are generally expressed in terms of radiant exposure ($J \cdot m^{-2}$) or irradiance ($W \cdot m^{-2}$), it was necessary to convert the MPE values to radiance ($W \cdot m^{-2} \cdot sr^{-1}$). The radiance values are then plotted as a function of wavelength (See Clause E.3.)

Table E.1 presents radiance permissible exposure values as a function of wavelength for a 100 s exposure duration where α subtends an angle of greater than or equal to 100 mrad. The most restrictive limits, photochemical or thermal, are listed. Retinal photochemical hazard limits are in italics style.

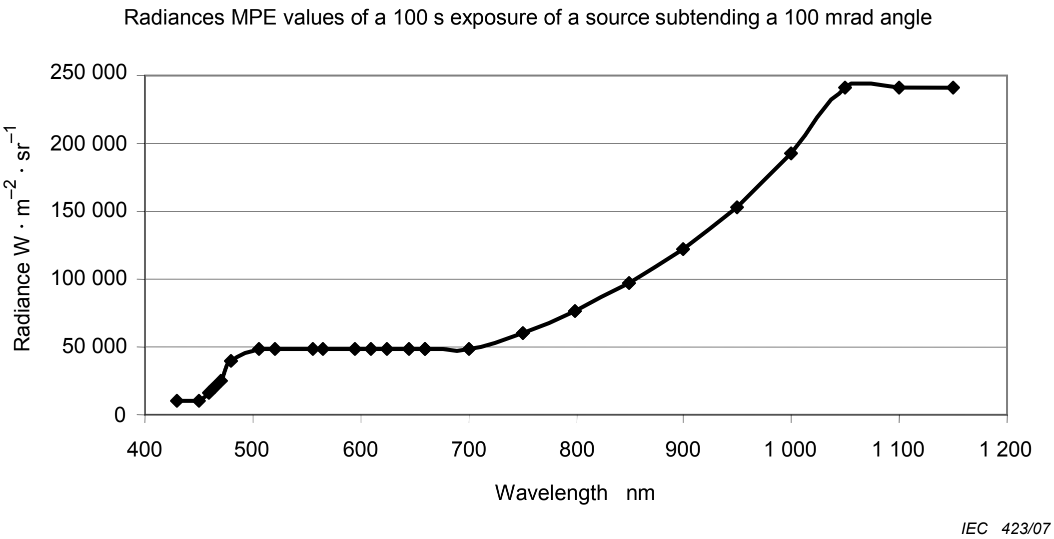


Figure E.1 – Radiance as a function of wavelength

Table E.1 – Maximum radiance of a diffused source for Class 1

Wavelength nm	Radiance $W \cdot m^{-2} \cdot sr^{-1}$	Radiance $W \cdot cm^{-2} \cdot sr^{-1}$
430	*10 000*	*1,00*
450	*10 000*	*1,00*
460	*15 848*	*1,58*
465	*19 952*	*2,00*
470	*25 119*	*2,51*
480	*39 811*	*3,98*
505	48 316	4,83
520	48 316	4,83
555	48 316	4,83
565	48 316	4,80
595	48 316	4,83
610	48 316	4,83
625	48 316	4,83
645	48 316	4,83
660	48 316	4,83
660	48 316	4,83
700	48 316	4,83
750	60 826	6,08
800	76 576	7,66
850	96 403	9,64
900	121 365	12,13
950	152 789	15,28
1 000	192 350	19,24
1 050	241 580	24,16
1 100	241 580	24,16
1 150	241 580	24,16
Figures in italics indicate retinal photochemical hazard limits.		

E.3 Rationale

The radiance values are calculated using IEC/ICNIRP MPE levels. As MPEs are generally expressed in terms of radiant exposure ($J \cdot m^{-2}$) or irradiance ($W \cdot m^{-2}$), it is necessary to convert the MPE values to radiance ($W \cdot m^{-2} \cdot sr^{-1}$). The radiance values are then plotted as a function of wavelength.

For MPEs expressed as irradiance, the following method to calculate radiance was used. Radiance is defined as:

$$L = \frac{d\ \Phi}{d\Omega \cdot dA \cdot \cos\theta} \qquad (E.1)$$

where Φ is the radiant power, Ω is a unit of solid angle, and A is the source size. MPEs are frequently expressed in terms of irradiance, which is defined as

$$E = \frac{\mathrm{d}\Phi}{\mathrm{d}A} \tag{E.2}$$

Substituting equation E.2 into equation E.1 yields radiance as a function of irradiance:

$$L = \frac{\mathrm{d}E}{\mathrm{d}\Omega \cdot \cos\theta} \tag{E.3}$$

We need to find the solid angle Ω and viewing angle θ. Substituting the following equation for Ω

$$\Omega = \frac{\pi\alpha^2}{4} \tag{E.4}$$

and assuming the worst-case viewing angle where $\theta = 0°$ (the viewer is looking directly into the beam), Equation E.3 reduces to

$$L = \frac{4E}{\pi\alpha^2} \tag{E.5}$$

For MPEs expressed as radiant exposure a slightly different method was used. Radiant exposure is defined as

$$H = \frac{\mathrm{d}Q}{\mathrm{d}A} \tag{E.6}$$

where Q is radiant energy expressed in Joules. Dividing by time yields

$$\frac{H}{\mathrm{d}t} = \frac{\mathrm{d}Q}{\mathrm{d}A \cdot \mathrm{d}t} \tag{E.7}$$

As radiant power is expressed as

$$\Phi = \frac{\mathrm{d}Q}{\mathrm{d}t} \tag{E.8}$$

equation E8 can be substituted into equation E.7, yielding

$$\frac{H}{\mathrm{d}t} = \frac{\mathrm{d}\Phi}{\mathrm{d}A} \tag{E.9}$$

Returning to equation E.1, we substitute equation E.9 to yield

$$L = \frac{\mathrm{d}\,H}{\mathrm{d}\Omega \cdot \mathrm{d}t \cdot \cos\theta} \tag{E10}$$

Again substituting equation E.4 and assuming the worst-case scenario of $\theta = 0°$, we obtain

$$L = \frac{4H}{\pi \alpha^2 t} \qquad \text{(E.11)}$$

For the calculations, we assumed a worst-case scenario of a 100 mrad angular subtense for an exposure duration of 100 s. The results are listed in Table E.1 and plotted in Figure E.1.

Annex F
(informative)

Summary tables

Table F.1 summarizes the physical quantities referred to in this Part 1, and gives the unit (and the symbol for the unit) used for each of them. The definitions of the SI base units are taken from ISO 1000. The units and symbols are taken from IEC 60027-1. Table F.2 summarizes the manufacturer's requirements.

Table F.1 – Summary of the physical quantities used in this Part 1

Quantity	Name of unit	Unit symbol	Definition
Length	metre	m	The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second
	millimetre	mm	10^{-3} m
	micrometre	µm	10^{-6} m
	nanometre	nm	10^{-9} m
Area	square metre	m^2	1 m^2
Mass	kilogram	kg	The mass equal to the mass of the international prototype of the kilogram
Time	second	s	The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state caesium-133 atom
Frequency	hertz	Hz	The frequency of a periodic phenomenon equal to one cycle per second
Plane angle	radian	rad	The plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius
	milliradian	mrad	10^{-3} rad
Solid angle	steradian	sr	The solid angle which, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere
Force	newton	N	1 $m \cdot kg \cdot s^{-2}$
Energy	joule	J	1 N·m
Radiant exposure	joule per square metre	$J \cdot m^{-2}$	1 $J \cdot m^{-2}$
Integrated radiance	joule per square metre per steradian	$J \cdot m^{-2} \cdot sr^{-1}$	1 $J \cdot m^{-2} \cdot sr^{-1}$
Power	watt	W	1 $J \cdot s^{-1}$
	milliwatt	mW	10^{-3} W
Irradiance	watt per square metre	$W \cdot m^{-2}$	1 $W \cdot m^{-2}$
Radiance	watt per square metre per steradian	$W \cdot m^{-2} \cdot sr^{-1}$	1 $W \cdot m^{-2} \cdot sr^{-1}$
NOTE For convenience, multiples and submultiples of units have been included where appropriate.			

Table F.2 – Summary of manufacturer's requirements

Requirements subclause	Classification						
	Class 1	Class 1M	Class 2	Class 2M	Class 3R	Class 3B	Class 4
Description of hazard class Annex C	Safe under reason-ably foreseeable conditions	As for Class 1 except may be hazardous if user employs optics	Low power; eye protection normally afforded by aversion responses	As for Class 2 except may be more hazardous if user employs optics	Direct intrabeam viewing may be hazardous	Direct intrabeam viewing normally hazardous	High power; diffuse reflections may be hazardous
Protective housing 4.2		Required for each laser product; limits access necessary for performance of functions of the products					
Safety interlock in protective housing 4.3	Designed to prevent removal of the panel until accessible emission values are below that for Class 3R				Designed to prevent removal of the panel until accessible emission values are below that for Class 3B or 3R for some products		
Remote Interlock 4.4	Not required					Permits easy addition of external interlock in laser installation	
Manual Reset 4.5	Not required						Requires manual reset if power interrupted or remote interlock is actuated
Key control 4.6	Not required					Laser inoperative when key is removed	
Emission warning device 4.7	Not required				Gives audible or visible warning when laser is switched on or if capacitor bank of pulsed laser is being charged. For Class 3R, only applies if invisible radiation is emitted		
Attenuator 4.8	Not required					Gives means to temporarily block beam	
Location controls 4.9	Not required				Controls so located that there is no danger of exposure to AEL above Classes 1 or 2 when adjustments are made		
Viewing optics 4.10	Not required		Emission from all viewing systems must be below Class 1M AEL				

Table F.2 *(continued)*

Requirements subclause	Classification						
	Class 1	**Class 1M**	**Class 2**	**Class 2M**	**Class 3R**	**Class 3B**	**Class 4**
Scanning 4.11	Scan failure shall not cause product to exceed its classification						
Class label 5.1 to 5.6	Required wording		Figures 1 and 2 and required wording				
Aperture label 5.7	Not required				Specified wording required		
Service access label 5.9.1	Not required	Required as appropriate to the class of accessible radiation					
Override interlock label 5.9.2	Required under certain conditions as appropriate to the class of laser used						
Wavelength range label 5.10 and 5.11	Required for certain wavelength ranges						
User information 6.1	Operation manuals must contain instructions for safe use. Additional requirements apply for Class 1M and Class 2M						
Purchasing and service information 6.2	Promotion brochures must specify product classification; service manuals must contain safety information						
Medical products 7.2	Not required					For the safety of medical laser products, IEC 60601-2-22 applies	

NOTE This table is intended to provide a convenient summary of requirements. See text of this standard for complete requirements.

Annex G
(informative)

Overview of associated parts of IEC 60825

The associated parts of IEC 60825 are intended for use in conjunction with the basic standard IEC 60825-1. Each part covers a defined scope and provides additional normative and informative guidance to enable the manufacturer and user to correctly classify and use the product in a safe manner by taking account of the particular conditions of use and competence/training of the operator/user. The information covered may include rationale, examples, clarification, methods, labelling, and any additional limits and requirements. See Table G.1.

Table G.1 – Overview of additional data in associated parts of IEC 60825

Part No.	Type	Description	Product designer	Product supplier	Product user	Safety critical component supplier	Test methods	Hazard assessment	Related standards
1	Standard	Equipment classification and requirements	Yes	Yes	Yes	Yes	Yes	Yes	
2	Standard	Safety of optical fibre communication systems (provides application notes and examples)	Yes	Yes	Yes	Yes	Yes	Yes	
3	Technical report	Guidance for laser displays and shows	No	No	Yes	No	No	Yes	
4	Standard	Laser guards (also addresses ability of high-power lasers to remove guard material)	Yes	Yes	Yes	Yes	Yes	Yes	
5	Technical report	Manufacturer's checklist for IEC 60825-1 (suitable for use in a safety report)	Yes	Yes	No	Yes	No	No	
6	Technical specification (withdrawn)								
7	Technical specification (withdrawn)								
8	Technical report	Guidelines for the safe use of medical laser equipment	No	No	Yes	No	No	No	IEC 60601-2-22
9	Technical report	Compilation of maximum permissible exposure to incoherent optical radiation (broadband sources)	No	No	Yes	No	Yes	Yes	
10	Technical report	Laser safety application guidelines and explanatory notes	Yes	Yes	No	No	Yes	No	ISO 13694
12	Standard	Safety of free space optical communication systems used for transmission of information	Yes	Yes	Yes	Yes	Yes	Yes	
14	Technical report	A user's guide	No	Yes	Yes	No	No	Yes	

NOTE This table is intended to provide an indication of content – see text of the particular standard for complete requirements. Some parts listed above may be under discussion by working groups and may not be formally published.

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IEC 60027-1, *Letter symbols to be used in electrical technology – Part 1: General*

NOTE Harmonized as EN 60027-1:2006 (not modified).

IEC 60065, *Audio, video and similar apparatus – Safety requirements*

NOTE Harmonized as EN 60065:2002 (modified).

IEC 60079 (all parts), *Electrical apparatus for explosive gas atmospheres*

NOTE Harmonized in EN 60079 series (partially modified).

IEC 60079-0:2004, *Electrical apparatus for explosive gas atmospheres – Part 0: General requirements*

NOTE Harmonized as EN 60079-0:2004 (not modified).

IEC 60204-1, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

NOTE Harmonized as EN 60204-1:2006 (modified).

IEC 60825-2, *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*

NOTE Harmonized as EN 60825-2:2004 (not modified).

IEC TR 60825-3, *Safety of laser products – Part 3: Guidance for laser displays and shows*

IEC 60825-4, *Safety of laser products – Part 4: Laser guards*

NOTE Harmonized as EN 60825-4:2006 (not modified).

IEC/TR 60825-5, *Safety of laser products – Part 5: Manufacturer's checklist for IEC 60825-1*

IEC/TR 60825-8, *Safety of laser products – Part 8: Guidelines for the safe use of laser beams on humans*

IEC/TR 60825-9, *Safety of laser products – Part 9: Compilation of maximum permissible exposure to incoherent optical radiation*

IEC/TR 60825-10, *Safety of laser products – Part 10: Application guidelines and explanatory notes to IEC 60825-1*

IEC 60825-12, *Safety of laser products – Part 12: Safety of free space optical communication systems used for transmission of information*

NOTE Harmonized as EN 60825-12:2004 (not modified).

IEC/TR 60825-13, *Safety of laser products – Part 13: Measurements for classification of laser products*

IEC/TR 60825-14, *Safety of laser products – Part 14: A user's guide*

IEC 60950 (all parts), *Information technology equipment – Safety*

NOTE Harmonized in EN 60950 series (modified).

IEC 61040, *Power and energy measuring detectors, instruments and equipment for laser radiation*

NOTE Harmonized as EN 61040:1992 (not modified).

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

NOTE Harmonized in EN 61508 series (not modified).

IEC 62115, *Electric toys – Safety*

NOTE Harmonized as EN 62115:2005 (modified).

IEC 62471:2006 (CIE S009:2002), *Photobiological safety of lamps and lamp systems*

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*

ISO 11146-1, *Lasers and laser-related equipment – Test methods for laser beam widths, divergence angles and beam propagation ratios – Part 1: Stigmatic and simple astigmatic beams*

NOTE Harmonized as EN ISO 11146-1:2005 (not modified).

IEC/ISO 11553-1, *Safety of machinery – Laser processing machines – Part 1: General safety requirements*

NOTE Harmonized as EN ISO 11553-1:2005 (not modified).

ISO 12100-1, *Safety of machinery – Basic concepts, general principles for design – Part 1: Basic terminology, methodology*

NOTE Harmonized as EN ISO 12100-1:2003 (not modified).

ISO 12100-2, *Safety of machinery – Basic concepts, general principles for design – Part 2: Technical principles*

NOTE Harmonized as EN ISO 12100-2:2003 (not modified).

ISO 13694, *Optics and optical instruments – Lasers and laser-related equipment – Test methods for laser beam power (energy) density distribution*

NOTE Harmonized as EN ISO 13694:2000 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-845	1987	International Electrotechnical Vocabulary (IEV) - Chapter 845: Lighting	–	–
IEC 60601-2-22	– [2]	Medical electrical equipment - Part 2: Particular requirements for the safety of diagnostic and therapeutic laser equipment	EN 60601-2-22	1996 [3]
IEC 61010-1	– [2]	Safety requirements for electrical equipment for measurement, control, and laboratory use - Part 1: General requirements	EN 61010-1 + corr. June	2001 [4] 2002

[2] Undated reference.

[3] Valid edition at date of issue. EN 60601-2-22:1996 will be superseded by EN 60601-2-22:200X, which is based on IEC 60601-2--22:2007.

[4] Valid edition at date of issue.

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